City of Santa Fe

NUTRIENT LOADING AND REMOVAL OPTIMIZATION STUDY

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City of Santa Fe

NUTRIENT LOADING AND REMOVAL OPTIMIZATION STUDY

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Abbreviations

AACE	Association for the Advancement of Cost Engineering
ADAF	average daily annual flow
ADMMF	average maximum month flow
aSRT	aerated solids retention time
BOD	biochemical oxygen demand
BNR	biological nutrient removal
C	Celsius
$CaCO_3$	calcium carbonate
Carollo	Carollo Engineers, Inc.
CBOD	carbonaceous biochemical oxygen demand
$CBOD_5$	5-day carbonaceous biochemical oxygen demand
City	City of Santa Fe
COD	chemical oxygen demand
cu ft	cubic feet
DAFT	dissolved air flotation thickener
DO	dissolved oxygen
EBPR	enhanced biological phosphorus removal
ECCV	East Cherry Creek Valley Water and Sanitation District
EI&C	electrical, instrumentation, and control
ffCOD	filtered flocculated chemical oxygen demand
GAO	glucose accumulating organisms
gpd	gallons per day
gpm	gallons per minute
HP	horsepower
HRT	hydraulic residence time
MBR	membrane reactors
MG	million gallons
mgd	million gallons per day
µg/L	micrograms per liter
mg	milligram
mg/L	milligrams per liter
MLR	mixed liquor recycle
MLSS	mixed liquor suspended solids
µm	micrometer
mm	millimeter
mV	millivolts
N	nitrogen
NH_4-N	ammonia
NMED	New Mexico Environment Department
NPDES	National Pollutant Discharge Elimination System
O&M	operation and maintenance

OP	ortho-phosphate
ORP	oxidation-reduction potential
P	phosphorus
PAO	phosphorus accumulating organisms
PLC	programmable logic controller
PM	project memorandum
ppd	pounds per day
PR WWTP	Paseo Real Wastewater Treatment Plant
psi	pounds per square inch
psig	pounds per square inch gauge
RAS	return activated sludge
rpm	revolutions per minute
SCADA	supervisory control and data acquisition
scfm	standard cubic feet per minute
sCOD	soluble chemical oxygen demand
SLR	solids loading rate
SMP	soluble microbial products
SNDN	simultaneous nitrification and denitrification
SRT	solids retention time
sq ft	square feet
sTKN	soluble Total Kjeldahl Nitrogen
Study	Nutrient Loading and Removal Optimization Study
SVI	sludge volume index
TIN	total inorganic nitrogen
TKN	Total Kjeldahl Nitrogen
TMDL	total maximum daily load
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
tSRT	total solids retention time
TSS	total suspended solids
USEPA	U.S. Environmental Protection Agency
UV	ultraviolet
VFA	volatile fatty acids
VFD	variable frequency drive
VSS	volatile suspended solids
WAS	waste activated sludge

EXECUTIVE SUMMARY

Introduction

The Paseo Real Wastewater Treatment Plant (PR WWTP), owned by the City of Santa Fe (City), has a permitted capacity of 13 million gallons per day (mgd) as average daily maximum month flow (ADMMF) and discharges into the lower Santa Fe River. The purpose of this Nutrient Loading and Removal Optimization Study (Study) is to develop and complete an evaluation of nutrient loadings and impacts within the receiving stream as well as the treatment facility and removal efficiencies of treatment processes at the PR WWTP. The main objectives of this Study were to understand what improvements are needed at the Plant to meet current and future discharge limits, and to develop an in-stream model that can be used to determine the impact of varying plant effluent concentrations on in-stream water quality.

The Study took place in five phases with the immediate objective to improve nutrient reduction performance through process optimization of the existing Plant (Phases 1 and 2). The next phases were designed to develop future treatment and discharge goals through engineering analysis and process modeling with the objective of identifying recommended treatment enhancements and/or modifications that were technologically achievable and financially feasible to reliably meet potential future treatment requirements (Phases 3 and 4). Phase 5 included development of this technical report. The five phases of the project are summarized below:

- Phase 1 – Existing Treatment Process Evaluation and Recommendations.
- Phase 2 – Implementation and Oversight of Recommendations.
- Phase 3 – Assimilative Capacity Study for Nutrient Loading to the Santa Fe River.
- Phase 4 – Viable Alternatives for Achieving Future Effluent Treatment Goals.
- Phase 5 – Final Report.

The findings from Phases 1, 2, and 4 of the project are included in this report (Phase 5). The findings from Phase 3 are included under separate cover.

Existing and Future Permit Limits

The City's Wastewater Management Division currently discharges effluent from the PR WWTP into the Santa Fe River Segment No. 113 under the National Pollutant Discharge Elimination System (NPDES) Permit NM002292. The current effluent nitrogen and phosphorus limits (which are not effective until July 2019 as per the compliance schedule included in the 2016 permit) of 6.9 milligrams per liter (mg/L) and 3.1 mg/L (30-day average) are based on the plant’s historical nutrient removal performance. The concentrations and load limits in the permit were based on the 95th percentile of each constituent. Mass limits included in the permit for BOD and TSS were calculated based on a design ADMMF of 8.5 mgd rather than the rated plant capacity of 13 mgd as flow projections over the planning horizon do not support higher flow projections.

In recent years, the New Mexico Environment Department (NMED) has developed an approach for deriving numeric nutrient impairment thresholds for surface waters in New Mexico. The state evaluated nutrient concentration data from reference streams (streams with minimal anthropogenic impacts) to determine acceptable nutrient concentrations. Streams with concentrations above the reference (background) ranges are considered to present possible threats to aquatic life designated uses. The proposed threshold concentrations for reference streams for the Santa Fe River, developed using reference values based on geology, slope, and altitude of stream, are 0.48 mg/L for total nitrogen (TN) and 0.09 mg/L for total phosphorus (TP).

These reference concentrations are currently considered to be the most stringent possible future effluent limits for the PR WWTP in future years. Actual limits likely will be developed based on waste load allocations in a future total maximum daily load (TMDL), and are expected to be more stringent than current permit limits, but possibly less stringent than these threshold values. Temporary standards are also being developed by NMED and the U.S. Environmental Protection Agency (USEPA) for TN and TP for the receiving stream, which could impact WWTP effluent limits.

Future permit limits for nutrients are anticipated to be implemented based on new TMDLs and the State's antidegradation provisions, which are intended to limit further degradation of state waters. New TMDLs are expected to be developed in the near future for the Santa Fe River. NMED and USEPA take into consideration limits of technology and economic factors when developing actual permit limits from TMDLs.

As future limits for TN and TP are thus uncertain at this time, Carollo Engineers, Inc. (Carollo) defined four effluent tiers for increasingly more stringent nutrient treatment requirements for the evaluations performed in this project (Table ES.1). These tiers are the basis for developing recommended process and treatment upgrades in Chapters 6 and 7 of this report. This approach provides the City with planning flexibility to meet potential future proposed limits and with the associated budgetary cost estimates to reach compliance.

Table ES.1 Technology-Based Effluent Tiers for Nitrogen and Phosphorus for Surface Water Discharge

Parameter	Status Quo	Tier 1	Tier 2	Tier 3	Tier 4
Representative Treatment Technology	Existing BNR Process	Optimization of Existing Process	MBR Treatment with Chemical Addition	Tertiary Treatment and Chemical Addition	Reverse Osmosis Treatment
TP, mg/L	1-5	<1	<0.5	<0.2	<0.1
TN, mg/L	5-7	3-5	2-4	2-3	<1

The City does not anticipate more stringent limits in the future for ammonia, metals, or temperature. Therefore, this study focuses exclusively on future compliance challenges related to TN and TP.

Influent Characterization

An influent characterization was performed for the PR WWTP in order to calibrate the process model that was used for the treatment capacity and process optimization evaluation. Special sampling was conducted in May 2017 on the primary influent, primary effluent, and filtrate.

The measured concentrations were generally in good agreement with the concentrations routinely measured in the plant influent. It was noted that, despite the facility's effort to generate volatile fatty acids (VFA) through primary sludge fermentation in the primary clarifiers, the data indicate that soluble organic carbon does not increase during primary clarification. In addition, belt filter press recycle was found to vary significantly in flows and composition.

Based on the influent characterization performed as part of this study, the following recommendations are made:

- Undertake a more detailed carbon mass balance across the primary clarification process to better understand how to maximize the VFA production and its benefit for the secondary treatment process.
- Continue the characterization of dewatering flows in the future on at least a monthly basis. Consider filtrate equalization along with side stream treatment for phosphorus removal.

Historical and Current Process Performance

The historical treatment performance of the liquid stream as it relates to ammonia (NH_4-N), nitrogen, and phosphorus removal was evaluated based on over 3 years of plant data (January 2014 to July 2017). This analysis served as the basis for developing and testing optimization strategies, as described in a subsequent section.

A summary of the treatment performance is as follows:

- Effluent ammonia concentrations have typically varied between 0 and 4 mg/L NH_4-N, with a 30-day running average concentration between 1 and 2 mg/L observed in recent years.
- Effluent nitrate/nitrite concentrations have ranged in recent years from about 1 to 4 mg/L with overall effluent TN concentrations of about 4 to 8 mg/L.
- Total phosphorus concentrations in the final plant effluent have ranged from less than 1 mg/L to 8 mg/L. Orthophosphate (OP) concentrations have ranged from less than 1 mg/L to 6 mg/L.

Nutrient profile testing was conducted in the secondary treatment process in June 2017 in order to better understand the existing nutrient removal efficiency prior to optimization efforts. Samples were taken in each of the passes of the aeration basins (A Pass, B Pass, C Pass, D Pass). The ammonia concentration profile revealed that nitrification performance was essentially completed in the A Pass and aeration in the B Pass was essentially unnecessary (ammonia profiles had already dropped well below 1 mg/L). The nitrate concentration profile showed that none of the grab samples contained significant amounts of nitrate. The nitrate profile indicated that one, if not both of the mixed liquor return (MLR) pumps could have been turned off during the sampling campaign with little anticipated change in the effluent quality. The OP concentrations in the secondary treatment system demonstrate the classical profile for effective enhanced biological phosphorus removal (EBPR) with very high phosphorus concentrations observed in the bioselectors due to phosphorus release by phosphorus accumulating organisms (PAO). OP was then quickly taken up in the aerobic zones and gradually dropped below 1 mg/L in the effluent of the aeration basin (end of C Pass).

Based on this evaluation, the following recommendations are made:

- Repeat the wastewater influent characterization of organic carbon that was conducted in May 2017, in later summer months in 2018 to assess the seasonal availability of organic carbon.
- Evaluate whether to adjust the return activated sludge (RAS) flows seasonally to maximize the acceptable sludge blanket depths for improved denitrification.

- Track nitrogen removal across the secondary clarifiers through grab samples or online instrumentation.
- Repeat profile testing in the South and North trains in the future and at different times (good or poor biological nutrient removal [BNR] performance, peak daily loading conditions, different seasonal conditions, weekend versus weekday, etc.) to better understand the effectiveness of each treatment zone for NH_4-N, nitrate, and phosphorus (P) removal.
- Conduct a microscopic evaluation of the activated sludge to assess whether glucose accumulating organisms (GAO) proliferate in the activated sludge at times of poor EBPR performance.

Process Modeling and Capacity Evaluation

A calibrated BioWin process model was developed to assess the secondary treatment capacity of the existing facility, and to assess possible process optimization strategies. The process model calibration was based on actual plant performance during the period between August 15, 2016 and June 15, 2017. A very good match was achieved between the historical data and the process model output. The deviations are generally less than 10 percent, which indicates a very good, industry-accepted calibration standard.

The process model calibration identified some uncertainties and gaps in the existing plant process data that would be helpful to address in order to refine further process-modeling efforts for future design purposes. It is recommended to collect the following process data in the future:

1. OP and TP concentrations in the secondary effluent (filter influent) to verify final effluent concentrations (i.e., sometimes the data indicate that TP in the secondary effluent is less than OP in the final effluent).
2. Diurnal dissolved oxygen (DO) profiles in the aeration basins throughout the seasons for more accurate process modeling. (This was subsequently implemented by installing DO probes in several zones in both basins.)
3. Conduct frequent total suspended solids (TSS) and chemical oxygen demand (COD) mass balances around the primary clarifiers to verify clarification performance, data reliability, and the effectiveness of in-situ fermentation.
4. Characterize the filtrate recycle streams periodically in the future.
5. Conduct influent sampling without filtrate periodically in the future (if sampling can be made possible) to help define the actual strength of the incoming domestic wastewater.
6. Consider a TSS analyzer for mixed liquor suspended solids (MLSS) monitoring in the aeration basins to track the operating solids retention time (SRT) better.

The calibrated process model was subsequently used to verify the design capacity of the primary and secondary processes at 13 mgd ADMMF assuming the current wastewater influent strength will remain comparable in future years, and that all units are in service. The primary treatment capacity is sufficient for the current hydraulic capacity rating. However, the secondary treatment capacity is insufficient to treat 13 mgd ADMMF at the current influent concentrations. At a minimum SRT of 10 days (the facility actually typically operates above this value in winter), the MLSS concentration and the solids loading rate (SLR) on the secondary clarifiers far exceeds recommended design guidelines. Process modeling predicts that the aeration basins can be operated at around 7.5 mgd ADMMF at an SRT of 10 days with a MLSS concentration of about 4,000 mg/L. Additional secondary treatment capacity could be gained by increasing the biochemical oxygen demand (BOD) and TSS removal efficiency in the primary clarifiers.

The following recommendations were made as part of the capacity evaluation:

- Determine whether the aeration basins can carry MLSS concentrations above 4,000 mg/L while still providing reliable treatment and acceptable sludge settling quality.
- Investigate anticipated future flows and loads in more detail when undertaking any aeration system upgrades or modifications in the near future to assure that the system will be designed for realistic design flows and loads.
- Revisit the required current minimum and adequate future design aeration capacity.

Process Optimization and Control

Several optimization opportunities for improving nutrient removal were identified for the PR WWTP based on the historical process performance analysis. These categories were grouped into ammonia removal, nitrogen removal, and phosphorus removal. Process synergies and competition between nitrification, denitrification, and phosphorus removal in the biological treatment system were discussed in detail. Individual treatment changes can have effects on multiple effluent parameters, as discussed further in Chapter 6.

The following recommendations were made for continued process optimization. Additional details are included in Chapter 6:

- Provide increased solids inventory control.
- Optimize the existing aeration system for both nitrification and denitrification.
- Consider surface wasting to control filament growth.
- Reduce impact of nutrient recycle in the filtrate stream through modified dewatering operations.
- Improve internal carbon management or external carbon addition for both denitrification and phosphorus removal.
- Adjust MLR flows to optimize nitrate return to the selector zones.
- Assess how operational modifications or process changes may increase or decrease the organic nitrogen (N) concentrations in the final plant effluent.
- Stabilize anaerobic conditions in selector zone.
- Avoid slug loads onto tertiary filtration that may result in the breakthrough of particulate P.

As part of this study, full-scale process optimization testing was conducted, focused on improvement of nitrification and denitrification. The following optimization strategies were implemented in 2017 and 2018:

1. Temporary offline storage of dewatering recycle flows.
2. Optimization of MLR flows.
3. Alternative aeration patterns in the aeration basins.

Key online instruments and analyzers were installed at the PR WWTP in advance of the tests in order to support the data evaluation and analysis. The results of these tests are summarized in Chapter 6.

Filtrate Offline Storage Testing

The following conclusions were gained from the filtrate offline storage testing:

1. The filtrate recycle stream adds significant P (and to a lesser extent N) loads to the plant influent. If sidestream treatment is considered, P removal should be prioritized.
2. Filtrate recycling is the main cause for influent load variability to the secondary treatment system. Peak influent loads on weekends coincide with effluent ammonia peaks. Filtrate flow equalization is recommended near-team to buffer out weekend spikes.
3. The testing period was too short to determine a statistically significant difference between baseline and testing performance.

MLR Flow Adjustments

Plant staff reduced MLR flows to the unaerated bioselectors by operating only one pump during the day, rather than two. Effluent nitrate was not negatively impacted by this flow reduction. Effluent TP improved noticeably and remained quite consistently below 0.5 mg/L since August 2017. Nitrate probe online data from the bioselector effluent can be useful to further optimize MLR flows in the future.

Alternative Aeration Patterns

The following conclusions were gained from testing alternative aeration patterns and DO setpoints:

1. Implementing an alternate aerobic/anoxic redox condition in the aeration basins is challenging at this time and proved ultimately unsuccessful given the current aeration system limitations. This would require aeration of the C Pass which is challenging for two reasons.
   a. DO control is very difficult in the C Pass and plant staff struggled to maintain minimum DO target set points.
   b. Aeration of this zone causes foam that is trapped in the aeration basins to leave over the basin effluent weir causing concerns of (temporarily or long-term) blinding the cloth filter screens.
2. Maintaining DO target concentrations in any of the zones throughout the day required constant operator attention and even then was nearly impossible. DO automation is required to be able to gain sufficient DO control in order to further lower TN effluent concentrations.
3. The DO profiles in the North and South Trains are significantly different. It is important to understand the cause of this discrepancy (unequal flow or load split, uneven air flow distribution). Automated DO control will help to balance out operation between both trains. Plant staff has recently installed a second ammonia probe and has relocated the nitrate probe from the bioselector to the north train.
4. Once DO control is automated, plant staff will have better aeration control to repeat testing of different aeration patterns and DO setpoints. It is recommended to combine such testing with profile testing throughout the basins in order to better understand where nitrification and denitrification is limited and make process adjustments accordingly.
5. Future aeration system modifications should include the ability for intermittent aeration of the aerated zones to improve simultaneous nitrification and denitrification (SNDN) operation (on/off cycling). Provisions for surface wasting would help minimize surface scum and improving sludge settling properties.

Capital Improvements for Achieving Future Effluent Nutrient Tiers

Capital improvements were recommended to achieve each of the future effluent nutrient tiers, as outlined in Table ES.1. Preliminary cost estimates were provided for each recommended project. Costs were developed based on a capacity of 13 mgd ADMMF. The Conceptual Design Cost Estimates provided herein represent an Association for the Advancement of Cost Engineering (AACE) Class 4 level of detail cost estimate prepared based on the conceptual design of the projects as outlined in herein. The Effective Price Level Date for the estimate is February 2018.

The recommended projects for the PR WWTP are grouped into four tiers of effluent limits and are summarized as follows:

- Tier 1 – Optimization of the existing process to achieve TP of less than 1 mg/L and TN of 3 to 5 mg/L:
  - Upgrades to aeration system.
  - MLR modifications.
  - Filtrate equalization.
  - Sidestream treatment.
- Tier 2 – Construction of additional processes to achieve TP of less than 0.5 mg/L and TN of 2 to 4 mg/L:
  - Membrane reactors (MBR) treatment with chemical addition.
- Tier 3 – Construction of additional processes to achieve TP of less than 0.2 mg/L and TN of 2 to 3 mg/L:
  - Tertiary treatment with chemical addition.
- Tier 4 – Construction of additional processes to achieve TP of less than 0.1 mg/L and TN of less than 1 mg/L:
  - Membrane filtration/reverse osmosis treatment.

A summary of the project costs for each tier is presented in Table ES.2.

Table ES.2 Project Cost Summary

Tier/Project	Cost
Tier 1 – Aeration Upgrades	$1,296,000
Tier 1 – MLR Modifications	$555,000
Tier 1 – Filtrate Equalization	$1,710,000
Tier 1 – Sidestream Treatment	$5,026,000
Tier 1 Total	**$8,587,000**
Tier 2 – Chemical Facilities	$3,939,000
Tier 2 – Membrane Filtration	$31,074,000
Tier 2 Total	**$35,013,000**
Tier 3 – Chemical Facilities	$3,939,000
Tier 3 – Tertiary Filtration	$14,479,000
Tier 3 Total	**$18,418,000**
Tier 4 – Membrane Filtration/Reverse Osmosis	$86,688,000
Tier 4 Total	**$86,688,000**

Figure ES.1 presents a graphical summary of costs for each effluent tier, and the respective effluent nitrogen and phosphorus concentrations that can be expected to be achieved. The costs for Tier 1 projects were added to Tiers 2 and 3 for comparison. Tier 1 projects are not required for Tier 4.

Tier 4 is the scenario that the City would face if NMED chooses to use their Reference Values and not look at Temporary Standards. These units are not achievable without the use of reverse osmosis.

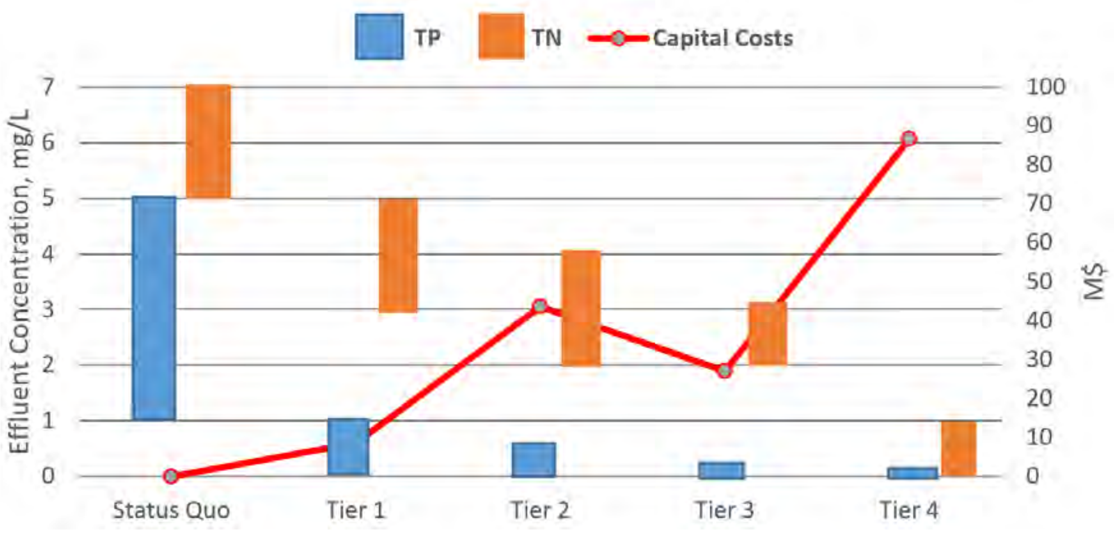

Figure ES.1 Summary of Project Costs

Chapter 1

PROJECT BACKGROUND

1.1 Introduction

The Paseo Real Wastewater Treatment Plant (PR WWTP), owned by the City of Santa Fe (City), was originally constructed in 1963 as a trickling filter plant and has been updated over the years to maintain compliance with local, state and federal requirements. The current facility is an activated sludge plant with primary clarification, tertiary filtration, and ultra-violet (UV) light disinfection. The PR WWTP discharges into the lower Santa Fe River. This segment of river is currently listed as "impaired" for nutrient/eutrophication as well as *E. coli* bacteria. The Wastewater Management Division received renewal of National Pollutant Discharge Elimination System (NPDES) Permit 0022292 in 2016. This permit has new discharge limits for total nitrogen (TN) and total phosphorus (TP) along with a 3-year compliance schedule. These limits are believed to be achievable through optimization of existing removal processes.

The purpose of this Nutrient Loading and Removal Optimization Study (Study) is to develop and complete an evaluation of nutrient loadings within the receiving stream as well as the treatment facility and removal efficiencies of treatment processes at the PR WWTP. The project consists of an Assimilative Capacity Study for nutrient loading in the Santa Fe River as well as a comprehensive review and evaluation of the nutrient removal process within the facility.

The Study took place in five phases with the immediate objective to improve nutrient reduction performance through process optimization of the existing Plant (Phases 1 and 2). The next phases were designed to develop future treatment and discharge goals through engineering analysis and modeling with the objective of developing treatment enhancements and/or modifications to reliably meet the future treatment goals (Phases 3 and 4). Phase 5 included development of this technical report. The five phases of the project are summarized below:

- Phase 1 – Existing Treatment Process Evaluation and Recommendations.
- Phase 2 – Implementation and Oversight of Recommendations.
- Phase 3 – Assimilative Capacity Study for Nutrient Loading to the Santa Fe River.
- Phase 4 – Viable Alternatives for Achieving Future Effluent Treatment Goals.
- Phase 5 – Final Report.

The findings from Phases 1, 2, and 4 of the project are included in this report. The findings from Phase 3 will be included under separate cover.

1.2 Project Objectives

The main objectives of this Study were to understand what improvements are needed at the Plant to meet current and future discharge limits, and to develop an in-stream model that can be used to determine the impact of varying Plant effluent limits on in-stream water quality.

Specifically, the City of Santa Fe team members listed the following project goals at the onset of this project:

1. Current Treatment Optimization:
   a. Identify what it will take to optimize the treatment system to reduce nutrient discharge;
   b. Understand the facility performance and operational practice more comprehensively to increase the staff confidence in plant operations and decision making; and
   c. Develop recommendations on how the existing facility can be operated to its best potential to put the WWTP in a better position for standard development in the future.
2. Plant Data and Process Control:
   a. Identify specific sampling locations recommended for improved process control;
   b. Recommend additional laboratory analysis and parameters that may help to optimize the system performance further; and
   c. Suggest additional instrumentation for improved monitoring and plant process control.
3. Develop Recommendations for Future Process Improvements:
   a. Use process modeling to inform the strategic planning and implementation of future projects; and
   b. Develop viable alternatives for future improvements to reduce nutrient discharges further beyond optimization.

1.3 Report Organization

This report is organized in the following eight chapters.

Chapter 1 introduces the project background, purpose, and objectives, as well as the PR WWTP treatment process and summarizes relevant process design criteria.

Chapter 2 summarizes the current and anticipated future effluent limits.

Chapter 3 summarizes the influent flows and loads from previous studies and characterizes the plant influent.

Chapter 4 reviews and discusses historical plant performance with regard to current and future nutrient compliance.

Chapter 5 summarizes the capacity evaluation of the secondary treatment process based on process modeling results.

Chapter 6 discusses opportunities for process optimization and summarizes the results of full-scale optimization testing that was completed during this project at the PR WWTP.

Chapter 7 develops alternatives and recommendations for achieving tighter future effluent limits for nitrogen and phosphorus. Capital cost estimates are provided for each recommended improvement.

1.4 Existing Plant Description

The PR WWTP is located at 73 Paseo Real, Santa Fe, New Mexico 87507. The WWTP has a conventional biological nutrient removal (BNR) treatment process and a rated design flow capacity of 13 million gallons per day (mgd) as average daily maximum month flow (ADMMF). The WWTP serves a residential population of 85,000 and treats the increased flows of tourists and visitors. Figure 1.1 shows the facility site layout with current treatment facilities and Figure 1.2 shows the current process flow schematic of the PR WWTP.

Figure 1.1 Paseo Real WWTP Site Layout

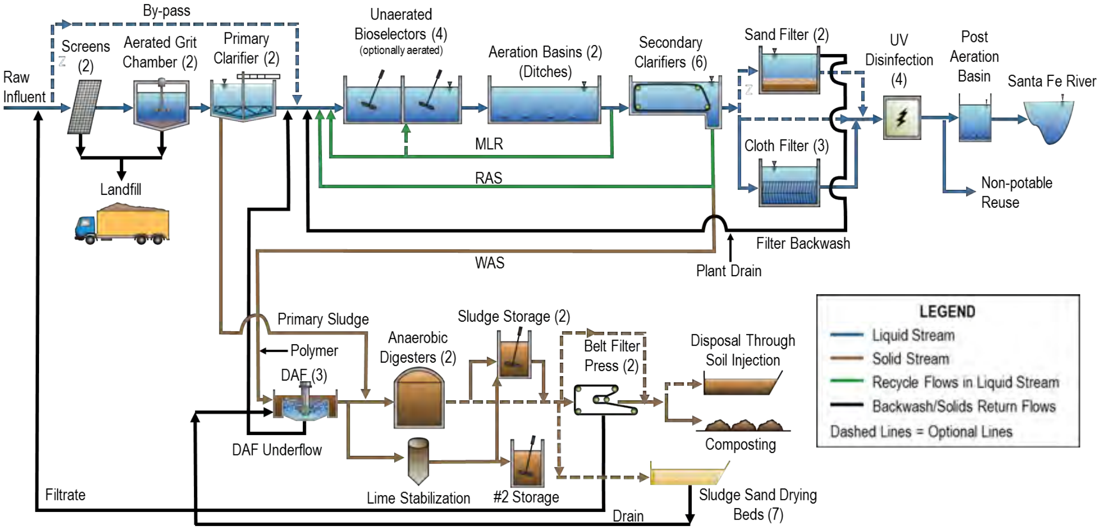

Figure 1.2 Process Flow Diagram of the Existing Paseo Real WWTP

1.5 Treatment and Process Description

1.5.1 Headworks and Grit Removal

Raw wastewater enters the headworks and passes through two fine screens (6-millimeter [mm] opening). Recycle streams from dewatering (filtrate from the belt filter presses and washwater) are returned to the headworks and combined with the raw wastewater upstream of the bar screens. The compliance influent sample is collected just downstream of the bar screens as a manually collected flow weighted composite sample by operations staff. This sample contains the plant internal dewatering recycle stream. Plant staff is not able to reliably collect samples upstream of the bar screens with an autosampler.

The screened wastewater passes through a Parshall flume for flow metering prior to being pumped to two aerated grit tanks. A grit washer removes organic matter that is recycled back to the liquid stream treatment process. Separated and cleaned grit is transported to a dumpster and landfilled.

1.5.2 Primary Treatment

From the headworks, the wastewater passes through a splitter box and is treated in the primary clarifiers. The WWTP has two equally sized primary clarifiers and typically operates one of the two units. Operations staff holds a sludge blanket in the operating clarifier to promote breakdown of organic material for better nutrient removal in the secondary treatment process. Primary sludge is sent directly to the anaerobic digesters. Surface scum is pumped from the scum pit to the digesters as well. Table 1.1 summarizes the relevant primary clarifier design criteria.

Table 1.1 Primary Clarifier Design Criteria

Process Element	Units	Design Criteria
Number of Units	-	2
Volume, each	gal	580,600
Diameter	feet	94
Side Water Depth	feet	10.5

1.5.3 Secondary Treatment

Primary effluent is routed to a rapid mix tank where it is blended with return activated sludge (RAS), mixed liquor return (MLR), tertiary filter backwash, and dissolved air flotation thickener (DAFT) underflow. The secondary influent flow is then routed through the anoxic bioselector basins. These selectors comprise of four equal sized basins (two basins per train) that can be operated as either aerated or anoxic basins.

Effluent from the bioselector basins collects in an effluent channel and is split into the two aeration basin trains (north and south trains), each of which has the configuration of a four-pass carrousel oxidation ditch (see Figure 1.3). Fine bubble Sanitaire diffusers are located in Passes A, B, and C. Air is provided by three Turblex Blowers or alternatively by four blowers located in the blower building that is located to the east of the bioselectors. RAS can be chlorinated to control the growth of filamentous organisms.

There are three large Hoffman blowers and two small PD Sutorbilt blowers. Operations staff report that the biggest problem using them for aeration basin air is the single speed. The

Sutorbilts do not provide much flexibility and do not match the variable air demand throughout the day. As they do not have a suction throttle valve, these blowers essentially run on or off.

Of the three Turblex blowers, one was recently rebuilt and this unit operates well. One of the other two units is not functional due to a malfunctioning control software. The third unit is functioning but unreliable as the blower trips off on occasion.

Mixed liquor is recycled from both aeration basins to the head of the bioselectors for nitrogen removal.

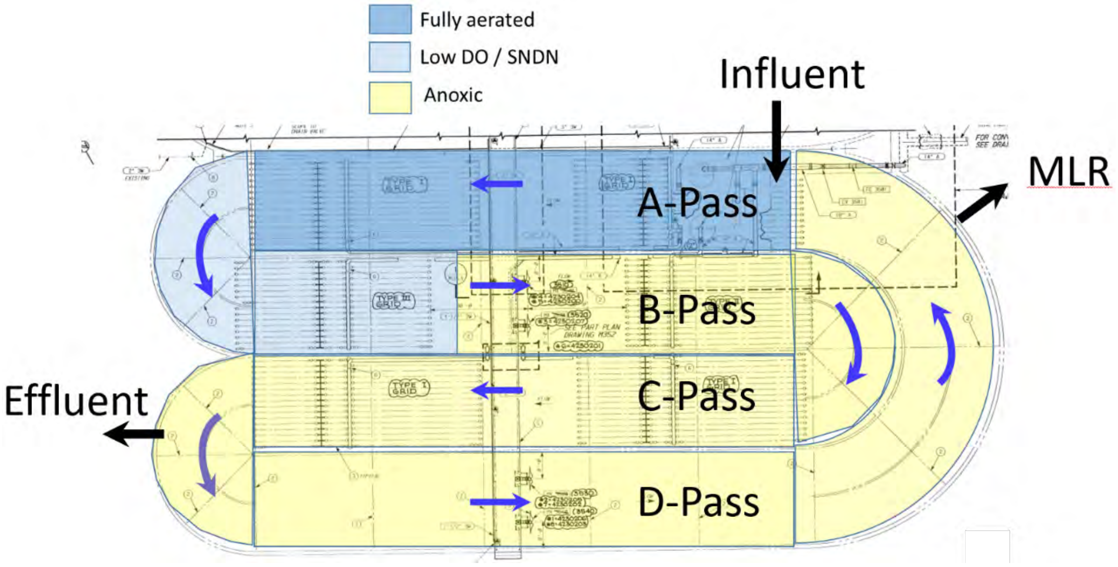

Figure 1.3 Configuration of the Aeration Basins and Aeration Pattern at Project Onset

Aeration basin effluent is combined and routed to six rectangular secondary clarifiers. Units 1 through 4 have vacuum mechanisms for sludge removal with integrated surface skimmers, Units 5 and 6 have skimmers and scrapers to remove floating solids.

Table 1.2 summarizes the relevant design criteria for the secondary treatment system.

Table 1.2 Secondary Treatment Design Criteria

Process Element	Units	Design Criteria
Bioselectors		
Number of Units	-	4 (two per train)
Volume, each	gallon	325,000
Aeration Basins		
Number of Units	-	2
Volume, each	mgd	3.26
Side Water Depth	feet	16.3
Blowers		
Number of Units	-	3 Hoffmans 2 Sutorbilts
Type	-	Single Speed, no VFD

Table 1.2 Secondary Treatment Design Criteria (con't.)

Process Element	Units	Design Criteria
Power	HP / rpm	20 / 2,600 (Sutorbilts) 200 / 3,550 (Hoffman)
Design Pressure	psig	7.5 (Sutorbilts and Hoffman)
Capacity, each	scfm	230 cfm (Sutorbilts) 4,000 cfm (Hoffman)
Turblex Blowers		
Number of Units	-	3 Turblex Blowers (only on operational)
Type	-	Variable speed
Power	HP / rpm	300 / 3,571
Design pressure	psig	8.5
Capacity, each	scfm	3,333
Mixed Liquor Recycle		
Number of Pumps	-	5 (but only three units currently work)
Type	-	Flyght, Model 3300.181
Power	HP	45
Impeller	inch	10
Capacity, each	gpm	3,500 (5.04 mgd each)
Total Capacity	mgd	10.1 (two functional pumps)
Secondary Clarification		
Number of Units	-	6
Volume, each	gallon	460,000
Length x Width	feet x feet	170 x 32
Side Water Depth	feet	12.1
Return Activated Sludge		
Number of Pumps	-	3 centrifugal pumps
Capacity, each	gpm	4,000
Total Capacity	gpm	6,000

Notes:

gpm	gallons per minute	HP	horsepower	psig	pounds per square inch gauge
rpm	revolutions per minute	scfm	standard cubic feet per minute	VFD	variable frequency drive

1.5.4 Tertiary Filtration

Secondary clarified effluent enters the influent channel to the two sand filters and the three disc filter tanks. In case of an emergency, tertiary filtration can be by-passed. The sand filters are typically not in operation as they cannot handle the fully rated facility capacity and have mechanical problems. Backwash flow from the filters is routed back to the secondary influent rapid mix tank.

Table 1.3 summarizes the relevant design criteria for the tertiary filtration system.

Table 1.3 Tertiary Treatment Design Criteria

Process Element	Units	Design Criteria
Disc Filters		
Number of Units	-	3
Filter Size	µm	10
Capacity, each	mgd	3 (average flow) 6.8 (peak flow)
Surface Area, each	sq ft	783
Sand Filters (not in operation)		
Number of Units	-	2
Volume, each	gallon	119,725
Capacity, each	mgd	5.4 (peak flow)
Surface Area, each	sq ft	1,568

Notes:

µm	micrometer	sq ft	square feet

1.5.5 Disinfection, Reaeration, Discharge, and Effluent Reuse

Tertiary effluent is disinfected through UV radiation. Effluent is then reaerated in the Post Aeration Basins to meet a 5 mg/L dissolved oxygen concentration before discharge into the Santa Fe River. Aeration is provide via two separate Aerzen Delta air blowers (1 duty plus 1 standby). Plant effluent then flows through the effluent Parshall flume for flow metering.

A portion of the filtered and disinfected effluent from the effluent channel is pumped offsite for non-potable water reuse (e.g., golf course and sports field irrigation), and to supply plant-wide non-potable water for seal water. Up to half of the plant effluent is used in the summer months for irrigation, or approximately 20 percent annually.

1.5.6 Solids Handling

Secondary sludge is thickened in the clarifiers to about 0.5 percent. A portion of the RAS is wasted to the DAFT for thickening under polymer addition. Primary sludge and thickened secondary sludge is pumped to the two anaerobic digesters. Biogas is used for digester heating in the two boilers. The digesters are mixed through introduction of digester gas into mixing guns. Excess digester gas is flared.

Depending on the amount of scum and solids production, a portion of the primary and secondary sludge can be stabilized through lime addition. The biosolids are pumped into a holding tank and lime is added in batch operation to raise the pH to 12 for at least 2 hours.

Digested and lime stabilized sludge are then separately stored in sludge holding tanks prior to dewatering in the belt filter presses. Both digested and lime stabilized sludges are dewatered separately during each week. Lime stabilized sludge is dewatered as needed during the day on one of the two belt presses and land applied on the sludge field. Typically, one or two units are in operation during the day while dewatering digested sludge. This allows the facility to field apply some of the cake sludge, while the other cake sludge is composted. However, this operation also forces plant staff to constantly switch dewatering operation and polymer addition.

Dewatered sludge either is transported to the Compost Dewatering Facility or can be brought to the Sludge Injection Field in warmer summer months.

Table 1.4 summarizes the relevant design criteria for the solids handling processes.

Table 1.4 Solids Handling Process Design Criteria

Process Element	Units	Design Criteria
DAFT		
Number of Units	-	3
Dimensions (L x W x D)	feet x feet x feet	48 x 12 x 8 (2 units) 40 x 12 x 8.75 (1 unit)
Anaerobic Digesters		
Number of Units	-	2
Volume, each	gallon	462,000 (fixed cover digester) 453,000 (floating cover digester)
Diameter	feet	55
Depth	feet	26
VSS Destruction	%	>50
SRT	days	>15
Sludge Storage 1		
Volume	gallon	660,000 (Lime Stabilization)
Diameter	feet	55
Side Water Depth	feet	15
Sludge Storage 2		
Volume	gallon	1,618,000
Diameter	feet	90
Side Water Depth	feet	31.5
Belt Filter Press		
Number of Units	-	2
Belt Width	meter	2
Washwater Use	gpm	about 90

1.5.7 Process Metering, Sampling, and Instrumentation

Currently, the PR WWTP meters flow at the following locations:

- Plant influent (including dewatering recycle streams);
- Final effluent prior to discharge after reuse water is split off;
- Combined RAS flow;
- Waste activated sludge (WAS) flows to each DAFT unit;
- Combined sludge from the DAFTs and primary clarifiers to each anaerobic digester;
- Non-potable water use; and
- Sludge flows to the belt filter presses.

MLR flows are not measured.

At the start of this project, the facility collected the following process data:

- Dissolved oxygen (DO), pH, ammonia (NH_4-N, nitrite, and nitrate were monitored three times per day with grab samples that are analyzed manually using field meters and test kits and the average was reported as a daily value; and
- Composite samples are collected from the bar screen effluent (hand composite) and the final plant effluent (automatic composite sampler).

All other samples were collected as grab samples by hand. Figure 1.4 shows the locations in the treatment facility were process data was being collected at the start of this project. This historical data is further discussed in Chapter 4.

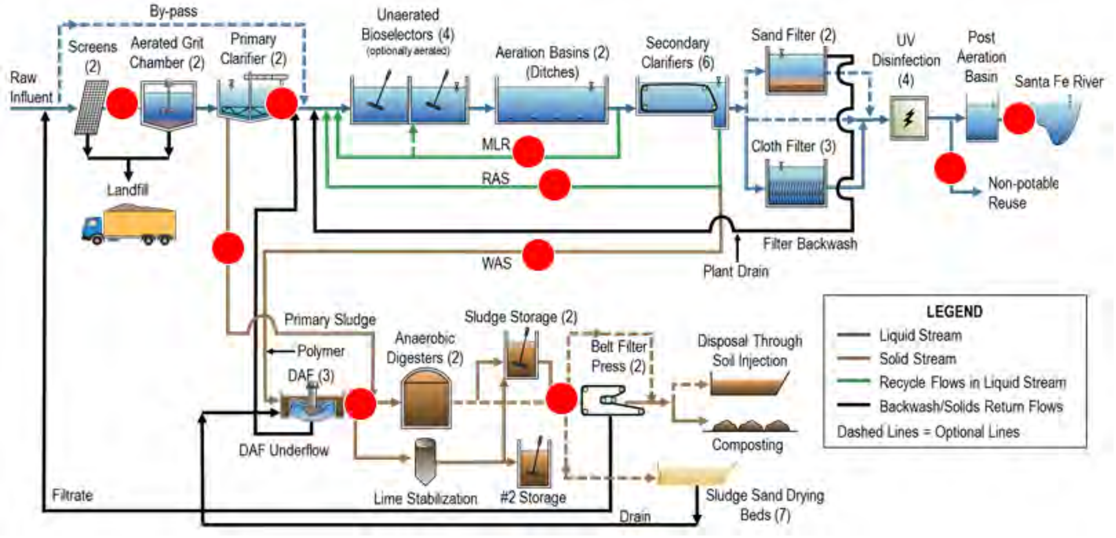

Figure 1.4 Process Data Sample Locations Indicated by Red Dots

1.5.8 Power Supply

The PR WWTP has two diesel-fueled generators and one natural gas fueled generator in case of a power supply emergency. The generators produce electricity for critical process equipment including a) the headworks building, grit blowers, and primary clarifiers; b) the DAFT, digesters, aeration basin blowers and mixers, and secondary clarifiers; and c) the disc filters and UV system.

The compost photovoltaic supplies virtually all of the power needs of composting. The second photovoltaic array supplies the rest of the plant with about 40 percent of its power requirements.

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Chapter 2

CURRENT AND ANTICIPATED FUTURE EFFLUENT LIMITS

2.1 Purpose

This chapter summarizes the current and anticipated future effluent limits for the PR WWTP with specific emphasis on nitrogen (N) and phosphorus (P) related limits.

2.2 Existing Permit Requirements

The City's Wastewater Management Division currently discharges effluent from the PR WWTP into the Santa Fe River Segment No. 113 under the NPDES Permit NM002292. The facility has a design capacity of 13 mgd ADMMF. The current permit was issued by the U.S. Environmental Protection Agency (USEPA) Region 6 on September 1, 2016 and expires on August 31, 2021.

Regulatory low flow for the stream segment of the Santa Fe River is zero and no dilution credits for meeting in-stream standards are granted for the PR WWTP. The segment includes the Santa Fe River and perennial reaches of its tributaries from the Cochiti Pueblo boundary upstream to the outfall of the PR WWTP. There is no regular flow downstream of the WWTP other than WWTP discharge and storm events. The discharge is located approximately 13 miles upstream of the Cochiti Reservoir. The Santa Fe River is designated for the following uses: irrigation, livestock watering, coolwater aquatic life, primary contact recreation, and wildlife habitat. Total maximum daily load (TMDL) limits were developed for *E. coli* in 2017. The segment has been listed for nutrient eutrophication since 2008, but TMDLs have not been prepared. The current effluent nitrogen and phosphorus limits are based on the existing plant’s capabilities (95 percent based on 2012 to 2014 data). Mass limits are calculated on 8.5 mgd rather than the rated plant capacity of 13 mgd. The pH standard and effluent limits range from 6.6 to 9.0.

The PR WWTP also has a groundwater discharge permit that was issued on April 25, 2016, and governs non-potable re-use applications.

Table 2.1 summarizes the existing permit load and concentration limits and respective averaging periods. The TN and TP load limits in the current permit were based on antidegradation limitations, using the 95th percentile of monitoring data from the last 3 years. Specific limits for nitrate, nitrite, and NH_4-N were not implemented for surface water discharge as the TN antidegradation value was considered to be protective.

Table 2.1 Current Permit Limits

Parameter	Load (ppd) 30-day Average	Concentration (mg/L) 30-day Average	Concentration (mg/L) 7-day Average
Discharge to Santa Fe River			
$CBOD_5$	709	10	15
TSS	2,127	30	45
TP	108	3.1	NA
TN	265	6.9	NA
E. coli	NA	126	410 (daily max.)
Dissolved Oxygen	Minimum 5 mg/L		
Total Residual Chlorine	NA	NA	11 µg/L (daily max.) (when used for cleaning)
Non-Potable Reuse			
TN			10 mg/L (max.)
Fecal Coliform Bacteria		100 Org/100 mL	200 Org/100 mL (max.)

Notes:

$CBOD_5$	5-day carbonaceous biochemical oxygen demand	mL	milliliter
TSS	total suspended solids		

Figures 2.1 and 2.2 illustrate the effluent limits for TN and TP concentrations based on the permitted TMDL.

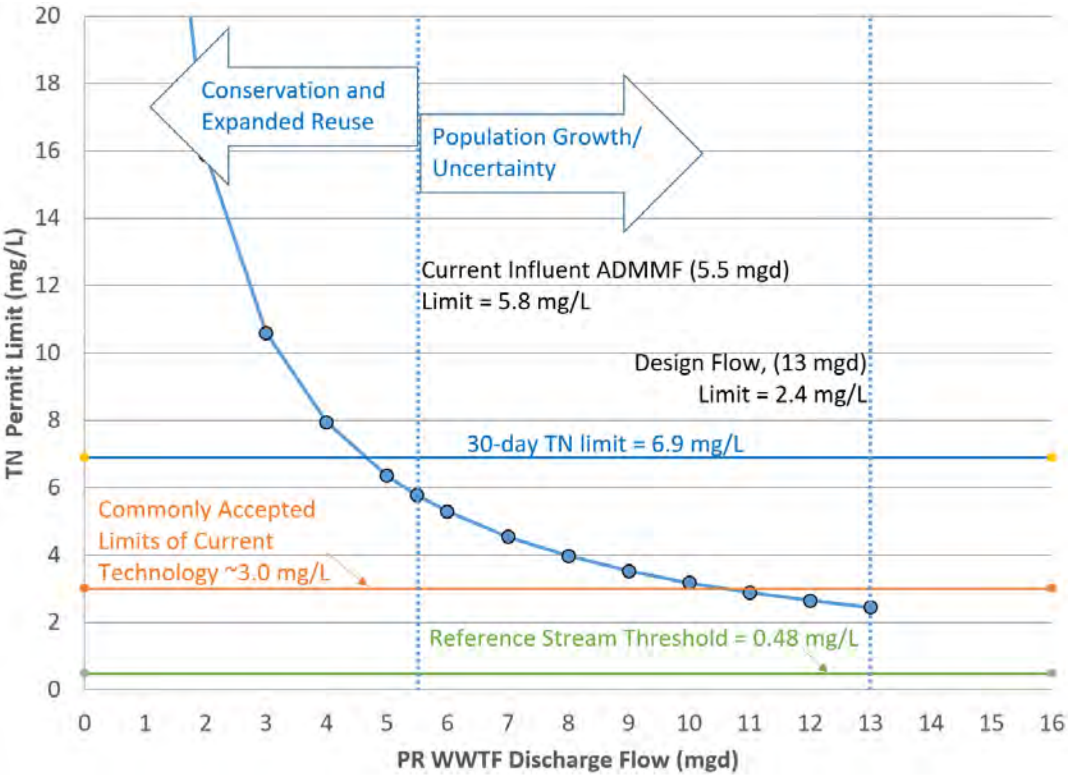

Figure 2.1 TN Permit Concentration Limit for Varying Effluent Flows Based on Permitted TMDL

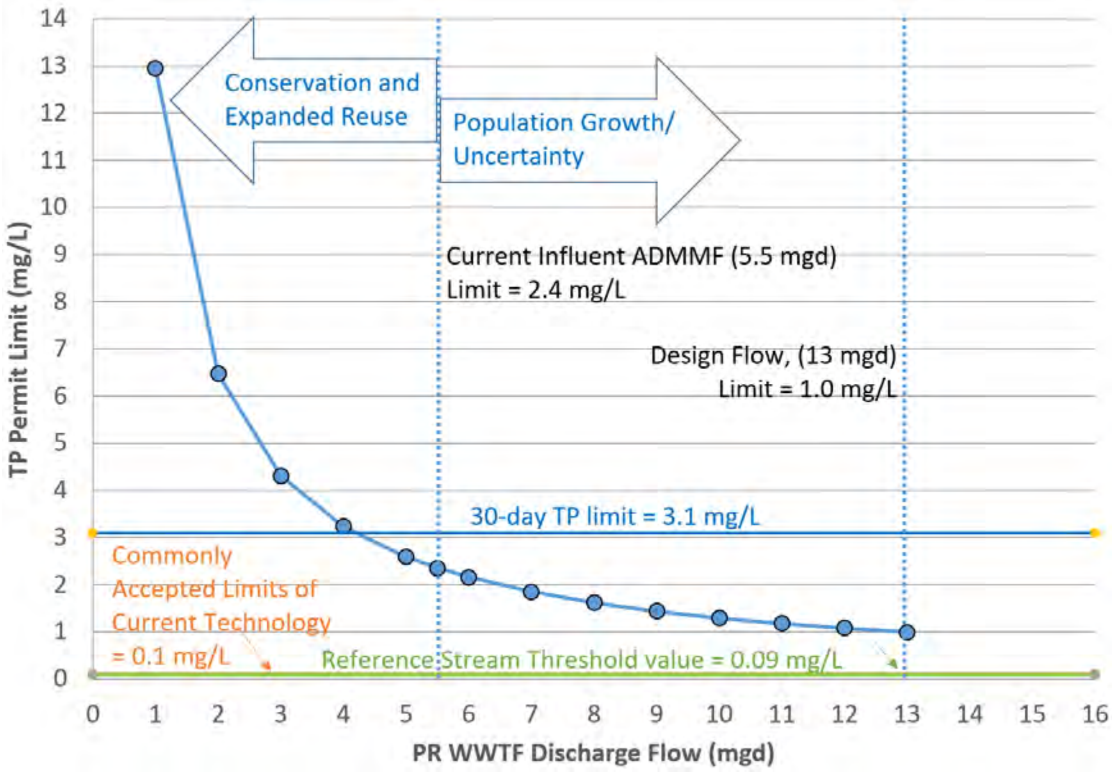

Figure 2.2 TP Permit Concentration Limit for Varying Effluent Flows Based on Permitted TMDL

2.3 Future Discharge Requirements

In recent years, the New Mexico Environment Department (NMED) has developed an approach for deriving numeric nutrient impairment thresholds for surface waters in New Mexico. The state evaluated nutrient concentration data from reference streams (streams with minimal anthropogenic impacts) to determine acceptable nutrient concentrations. Streams with concentrations above the reference ranges are considered to present possible threats to aquatic life designated uses. Table 2.2 summarizes the proposed threshold concentrations for reference streams for the Santa Fe River as developed by the NMED Surface Water Quality Bureau (June 1, 2016) from the New Mexico Plateau ecoregion.

Table 2.2 Proposed Future Nutrient Limits for Surface Water Discharge

Parameter	Reference Stream Threshold Concentrations
TP	0.09
TN	0.48

Notes:
(1) Reference: NMED Surface water Quality Bureau (2016). Refinement of Stream Nutrient Impairment Thresholds in New Mexico.

These reference concentrations currently are considered to be the most stringent possible future effluent limits for the PR WWTP in future years. Actual limits will likely be developed based on Waste Load Allocations in a future TMDL, and are expected to be more stringent than current permit limits, but possibly less stringent than these threshold values.

Future permit limits for nutrients are anticipated to be implemented based on new TMDLs and the State's antidegradation provisions, which are intended to limit further degradation of state waters. New TMDLs are expected to be developed in the near future for the Santa Fe River. NMED and EPA take into consideration limits of technology and economic factors when developing actual permit limits from TMDLs.

Since future limits for TN and TP are uncertain at this time, Carollo Engineers, Inc. (Carollo) defined four effluent tiers for increasingly more stringent nutrient treatment requirements for this project (Table 2.3). These tiers are the basis for developing recommended process and treatment upgrades in Chapters 6 and 7 of this report. This approach provides the City with planning flexibility to meet future proposed limits and with the associated budgetary cost estimates to reach compliance.

Table 2.3 Technology-Based Effluent Tiers for Nitrogen and Phosphorus for Surface Water Discharge

Parameter	Status Quo	Tier 1	Tier 2	Tier 3	Tier 4
Representative Treatment Technology	Existing BNR Process	Optimization of Existing process	Membrane Reactors (MBR) Treatment with Chemical Addition	Tertiary Treatment and Chemical Addition	Reverse Osmosis Treatment
TP, mg/L	1-5	<1	<0.5	<0.2	<0.1
TN, mg/L	5-7	3-5	2-4	2-3	<1

The City does not anticipate more stringent limits in the future for ammonia, metals, or temperature. Therefore, this study focuses exclusively on future compliance challenges related to TN and TP.

Chapter 3

INFLUENT CHARACTERIZATION

3.1 Purpose

This chapter summarizes the influent flow and load characteristics for the PR WWTP assumed for the process modeling evaluation used for the treatment capacity and process optimization evaluation presented in Chapters 5 and 6.

3.2 Current and Future Influent and Effluent Flows

The current influent flows and loads for the PR WWTP were are summarized below based on daily process data provided for a two year period from January 2015 to May 2017 (Table 3.1). Figure 3.1 shows the historical influent flows to the facility during this time period.

Due to non-potable water reuse in summer between the months of April to September, the effluent flows during this period were an average of only 4 mgd.

Table 3.1 Summary of Historical Influent Flows (2015-2017)

Flow	2015-2017
Average Daily Annual Flow (ADAF)	5.3
ADMMF	5.7
PDF	7.7

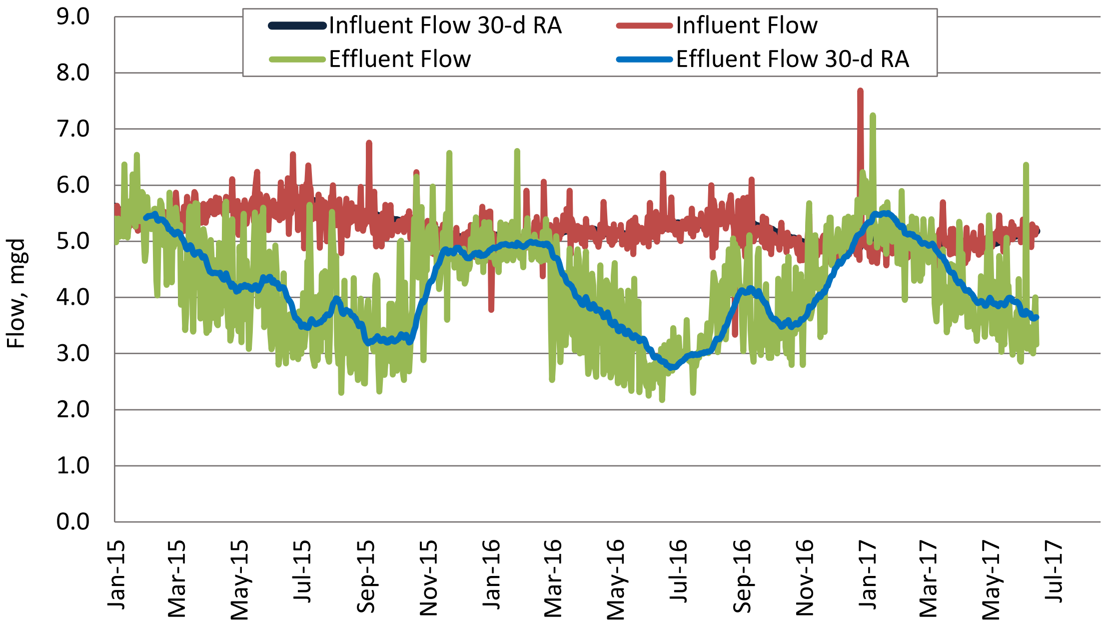

Figure 3.1 Influent and Effluent Flows (2015-2017)

The City's wastewater flows have remained relatively constant in past years due to slow population growth and emphasis on water conservative efforts. Future population growth is anticipated to remain around 1 percent per year and the City does not anticipate that the current treatment capacity of 13 mgd ADMMF will be exceeded within the 20-year planning horizon. Therefore, the design and budgetary cost development for recommended improvements in Chapter 7 is based on the current rated design capacity of 13 mgd ADMMF.

3.3 Current and Projected Influent Loads

The wastewater influent loads and concentrations were examined in this project to adequately characterize current and projected wastewater influent and recycle stream characteristics. The influent data collected by the PR WWTP staff includes the filtrate and washwater recycle streams from dewatering, which can carry significant ammonia and soluble phosphorus loads that affect the liquid stream treatment performance.

Figures 3.2 through 3.4 show the historical influent loads for organics, solids, nitrogen, and phosphorus compounds. Influent chemical oxygen demand (COD) loads dropped noticeably in summer 2016 which is attributed by plant staff to a change in the influent sampling location. Prior to summer 2016, the influent sampling location used to be just before the primary clarifiers. The current sampling location is considered to be more representative due to better hydraulic conditions. However, the current location includes the effect of the dewatering filtrate return, which is high in ammonia and increases the apparent strength of the total influent flow. In the future, options to reduce or eliminate this effect (discussed later in this report) include equalization of the filtrate return, sidestream treatment, and/or introduction of the flow further downstream in the aeration basin influent. Similarly, TSS and volatile suspended solids (VSS) influent concentrations were lower and more stable after summer 2016 compared to previous months (data not shown). It was concluded that influent data post August 2016 should be used for the process model calibration (see Chapter 5).

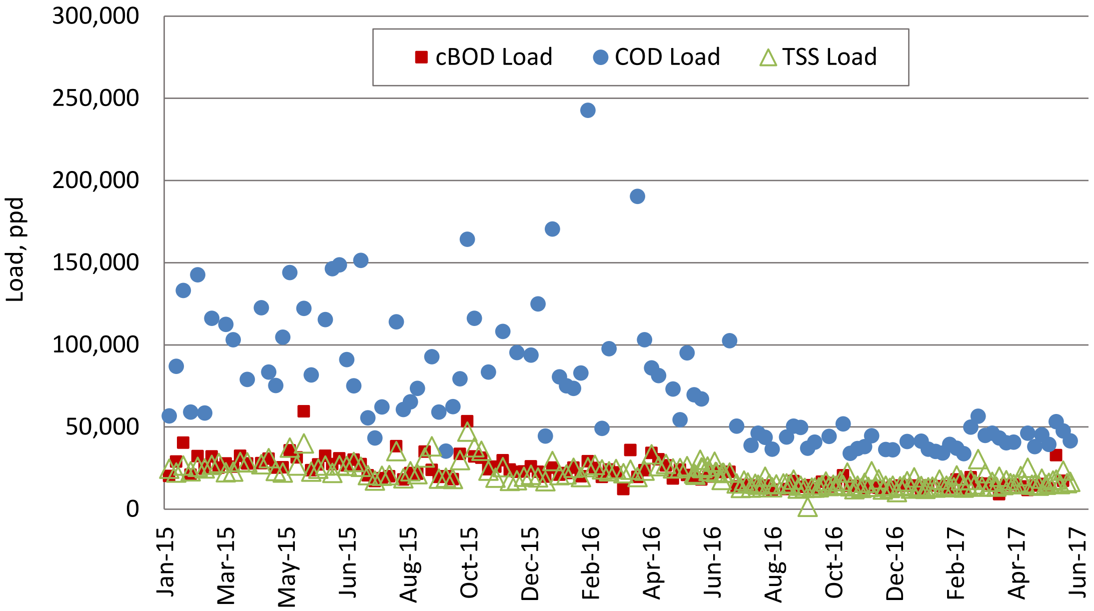

Figure 3.2 Influent Organic and Solids Loads (2015-2017)

The influent nitrogen loads have stayed relatively constant over the past years (Figure 3.3); however, greater fluctuations are observed for influent phosphorus loads (Figure 3.4). This is indication that filtrate recycles may carry significant phosphorus loads.

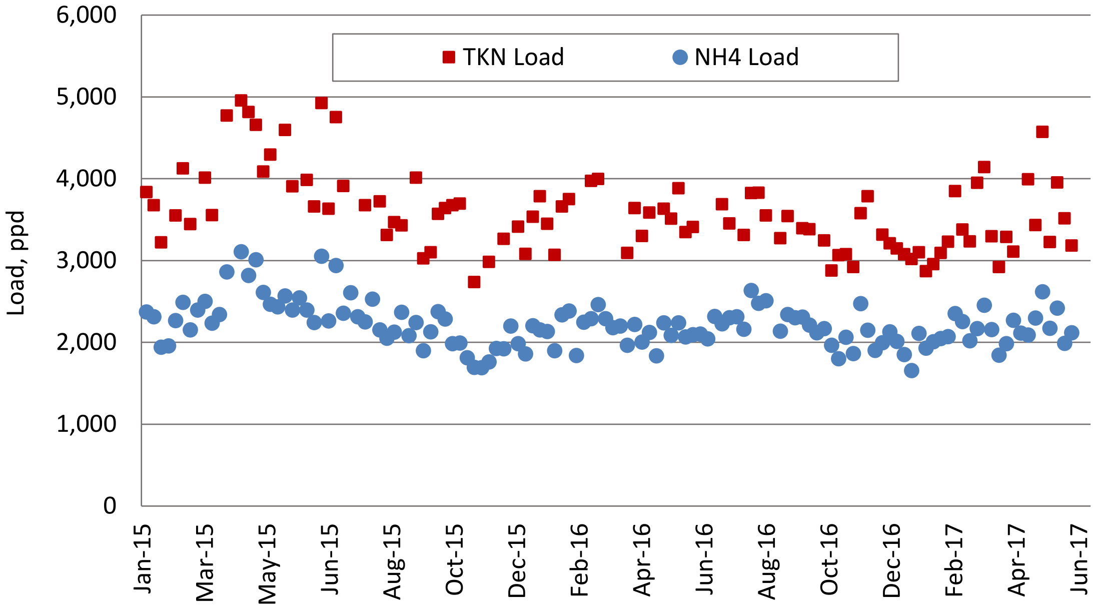

Figure 3.3 Influent Nitrogen Loads (2015-2017)

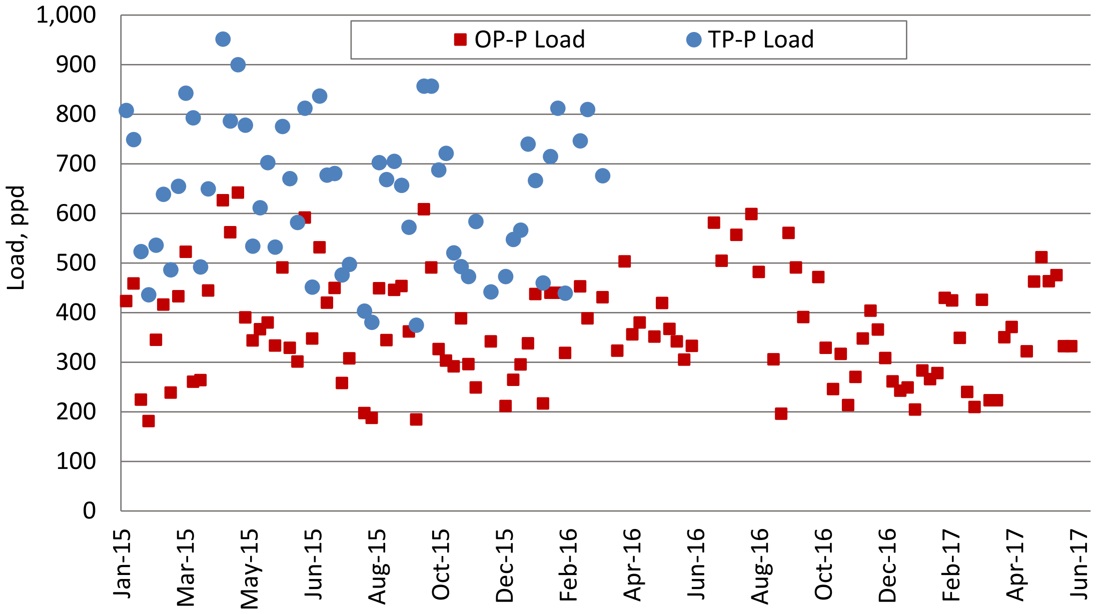

Figure 3.4 Influent Phosphorus Loads (2015-2017)

3.4 Special Influent Characterization

In order to better characterize the wastewater influent and filtrate recycle streams individually, additional sampling was undertaken in May 2017. Table 3.2 summarizes the results for primary influent, primary effluent, and filtrate as average concentrations.

Table 3.2 Influent Characterization Results (May 2017, n=9)

Parameter	Primary Influent	Primary Effluent	Filtrate Recycle (including washwater)
Flow	5.1 ± 0.16 mgd	NA	3,400 - 86,000 gpd
TSS	349.6 ± 28	202 ± 31	170 - 890
VSS	318.4 ± 25	175.6 ± 28	150-600
$CBOD_5$	355.4 ± 32	NA	NA
COD	870.3 ± 103	687.2 ± 65	310-420
sCOD	415.1 ± 39	419.1 ± 36	NA
ffCOD	260.4 ± 32	267.2 ± 34	NA
NH_4-N	49.5 ± 6	46.9 ± 6	NA
TKN	67.5 ± 12	55.9 ± 11	210-640
sTKN	56.4 ± 10	47.1 ± 13	NA
TP	12.5 ± 5	11.1 ± 3	160 - 680
OP	8.5 ± 3	8.5 ± 3	NA

Notes:

ffCOD	filtered flocculated chemical oxygen demand	gpd	gallons per day
OP	ortho-phosphate	sCOD	soluble chemical oxygen demand
sTKN	soluble Total Kjeldahl Nitrogen	TKN	Total Kjeldahl Nitrogen

Generally, the measured concentrations for TSS, VSS, $CBOD_5$, COD, NH_4-N, TKN, TP, and OP from this special sampling campaign are in good agreement with the concentrations routinely measured in the plant influent.

Primary effluent concentration measured are generally reasonable when compared to influent concentrations. Despite the facility's effort to generate volatile fatty acids (VFA) through primary sludge fermentation in the primary clarifiers, the data indicate that soluble organic carbon does not increase during primary clarification. VFA generation is important because this is the most readily available form of carbon for BNR. It is possible that any VFAs formed in the primary clarifier remain in the primary sludge blanket and are not mixed into the primary effluent.

Based on these results, it was recommended that the facility undertake a more detailed carbon mass balance across the primary clarification process to better understand whether VFAs are produced.

Belt filter press recycle flows varied significantly in flows and composition. Importantly, TKN and OP concentrations varied significantly, which is relevant for the performance of the secondary treatment process. Figure 3.5 illustrates the impact of the dewatering recycle flows on the OP concentration measured in the plant influent for the period in May 2017.

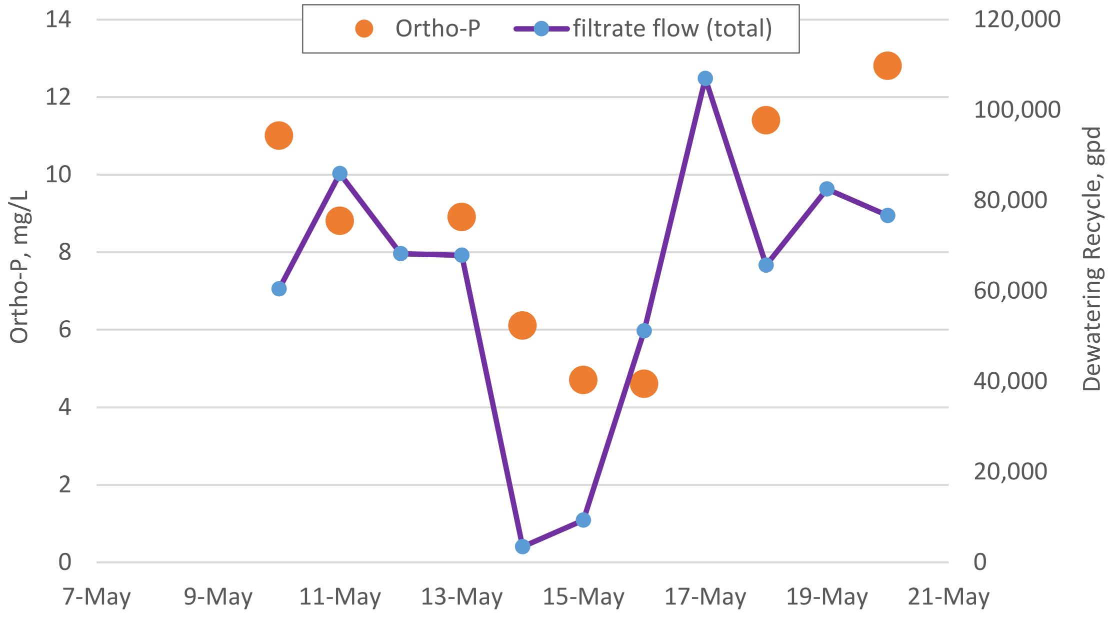

Figure 3.5 Impact of Dewatering Recycle Flows on Influent OP Concentration (May 2017)

It is recommended to continue the analysis of dewatering flows in the future on at least a monthly basis. Further, filtrate equalization should be considered in the future along with side stream treatment for phosphorus and nitrogen removal. A filtrate flow meter will be integrated as part of the current solids improvements project.

Based on the results presented in Table 3.2, influent fractions were calculated that characterize the influent at the PR WWTP and were adopted for the process model calibration presented in Chapter 5. These influent parameter fractions are presented in Table 3.3.

Table 3.3 Influent Parameter Fractions Based on May 2017 Special Sampling Campaign

Influent Fractions	Primary Influent	Comment
VSS/TSS	0.91	Typical for domestic WW
COD/cBOD$_5$	2.4	High end of typical range (2.0-2.3)
sCOD/COD	0.5	Typical
ffCOD/COD	0.3	Typical
NH$_4$/TKN	0.8	High end of typical range (0.7)
OP/TP	0.7	High end of typical range (0.5)

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Chapter 4

HISTORICAL AND CURRENT PROCESS PERFORMANCE

4.1 Purpose

This chapter discusses the historical treatment performance of the liquid stream as it relates to NH_4-N, N, and P removal. More than 2 years of plant data (January 2014 to July 2017) were evaluated in detail in support of this effort. As part of this project, the current process performance was also examined through a nutrient profile test in the bioselectors and aeration basins. Results from that sampling campaign are discussed and evaluated in this chapter as well. The analysis presented in this chapter served as the basis for developing and testing optimization strategies, which are further discussed in Chapter 6.

4.2 Nitrification Performance

Effluent NH_4-N concentrations have typically varied between 0 and 4 mg/L NH_4-N, with a 30-day running average concentration between 1 and 2 mg/L observed in recent years (Figure 4.1). In order to reduce TN in the plant effluent, it will be necessary to reduce ammonia well below 1 mg/L in the future. NH_4-N is removed through nitrification, which depends on four process factors that are discussed in the following:

- Sufficient alkalinity;
- Sufficient aerated solids inventory to allow for adequate levels of nitrifiers;
- Adequate DO supply; and
- Secondary influent TKN load fluctuations.

Temperature is also an important factor for nitrification, with higher retention times required at lower temperatures for nitrifier growth.

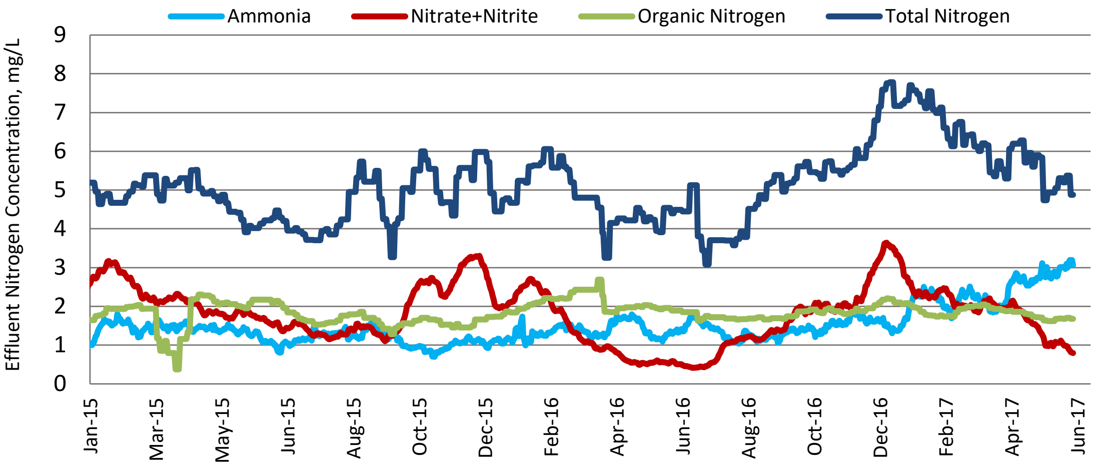

Figure 4.1 Effluent Nitrogen Concentrations as 30-day Running Averages (2015-2017)

4.2.1 Alkalinity

Secondary effluent alkalinity should remain at minimum, above 50 to 70 mg/L as calcium carbonate ($CaCO_3$) so as not to limit the nitrification process. Effluent alkalinity at the PR WWTP has rarely dropped below 100 mg/L $CaCO_3$, and is therefore not of concern (Figure 4.2). Sufficient effluent alkalinity concentration is attributed to two main factors: high influent alkalinity, which typically ranges between 250 and 300 mg/L as $CaCO_3$; and robust denitrification in the aeration basins, which recovers one half of the alkalinity that is consumed per mole of ammonia nitrogen that is nitrified.

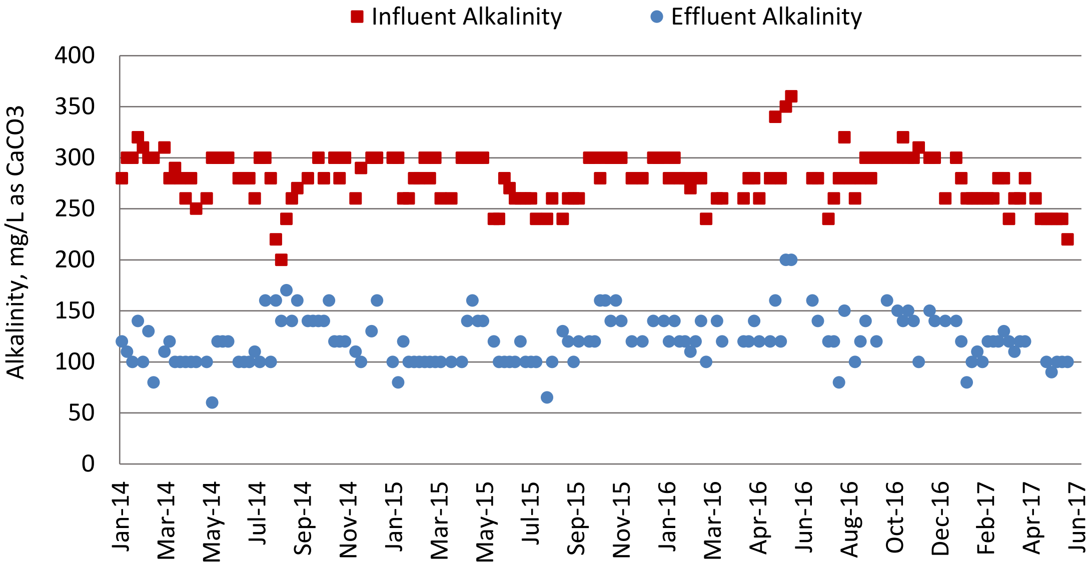

Figure 4.2 Influent and Effluent Alkalinity (2014-2017)

4.2.2 Aerated Solids Inventory

Compared to ordinary heterotrophic bacteria, nitrifiers are slow growing autotrohic organisms that need a minimum solids retention time (SRT) in the aeration basins to proliferate. Nitrifiers only grow in presence of NH_4-N or nitrite, and DO. Therefore, the total solids inventory in the secondary treatment system is of little relevance. Only the solids inventory under aeration should be considered when assessing if sludge age is sufficient for maintaining full nitrification (effluent NH_4-N less than 1 mg/L). In oxidation ditch systems operating under simultaneous nitrification and denitrification (SNDN) at very low DO concentrations the calculation of the fraction of the solids inventory that is under aeration becomes difficult.

Figure 4.3 shows the total SRT (tSRT) in the aeration basin and ammonia concentration in the effluent since 2015. The aerated SRT (aSRT) was calculated considering only the volume of Passes A and B in each basin since the facility has traditionally only aerated those two passes. The tSRT has fluctuated between 8 and 14 days, while the aSRT ranges from approximately 4 to 6 ays year-round.

Since about September 2015, the effluent NH_4-N concentrations have improved and consistently remained below approximately 2 mg/L. At the same time, the aSRT increased to an average of 8 days. This positive correlation between aSRT and effluent ammonia concentration may indicate that the aerated volume in the aeration basins may be too low to fully nitrify.

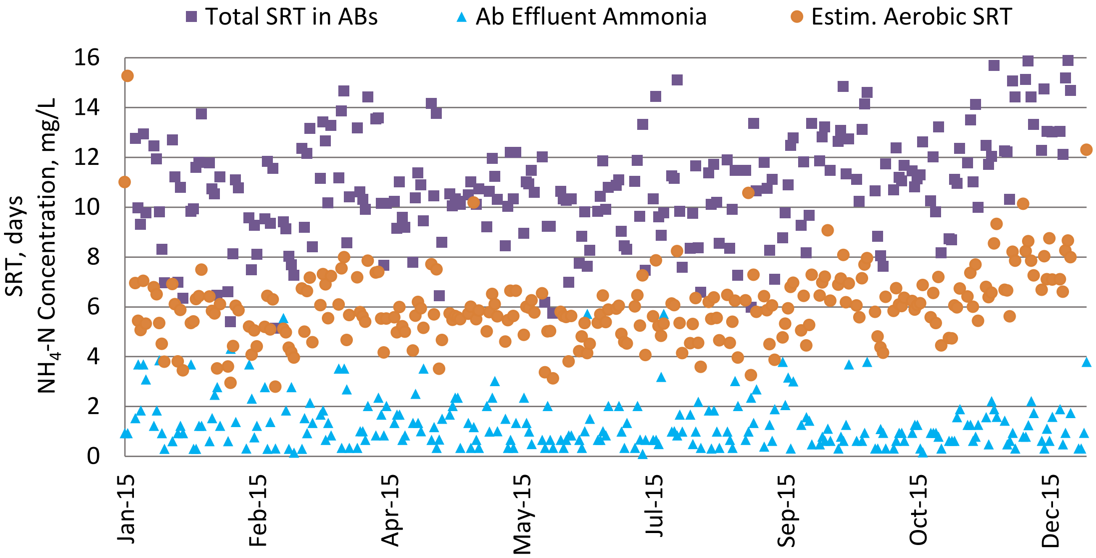

Figure 4.3 Effluent Ammonia versus Total and Aerobic Solids Residence Time (2015)

4.2.3 Dissolved Oxygen Supply and Aeration Control

As stated above, the facility has traditionally aerated only the first two passes in both aeration basins. Aeration has been controlled in the past to target effluent ammonia concentrations of about 2 mg/L in order to reduce nitrate concentrations in the final effluent and save aeration energy.

However, partial nitrification is not recommended as part of future operations when attempting to minimize effluent TN concentrations. It commonly results in variable effluent NH_4-N concentrations, thereby fluctuating effluent nitrate and potentially phosphorus concentrations. This makes it very difficult to stabilize effluent quality for stringent nutrient limits.

The historical DO concentrations in the South Aeration Basin Passes A and B are presented as an example of typical plant operation in Figure 4.4. During this period, aeration was controlled by measuring DO concentrations with a handheld probe at two monitoring locations in each basin (Figure 4.5) three times per day. Operations staff documented the average daily DO concentration, as well as high and low concentrations. According to data collected from April through May 2017, DO concentrations fluctuated in both passes between 0.5 and 2.5 mg/L. This indicates that aeration control is not optimized, as the target DO concentration ideally would be consistently maintained throughout the day. However, this level of aeration control cannot be achieved through manual adjustments throughout the day based on handheld DO readings. Automated control based on online DO measurements in the basins is required for more stable DO concentration. Nitrification is much more dependent on DO concentration than is the degradation of organics. The low measured DO values likely contribute to higher ammonia in the effluent. Inconsistent DO levels in the basins do not only effect nitrification but also denitrification and phosphorus removal.

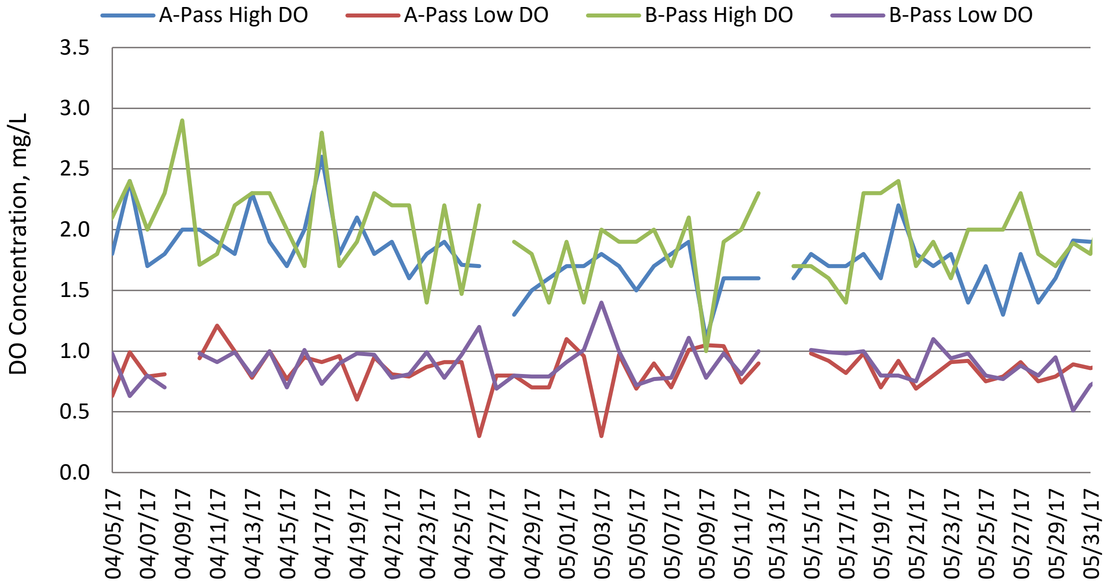

Figure 4.4 DO Concentrations in the South Aeration Basin A and B Pass (April-May 2017)

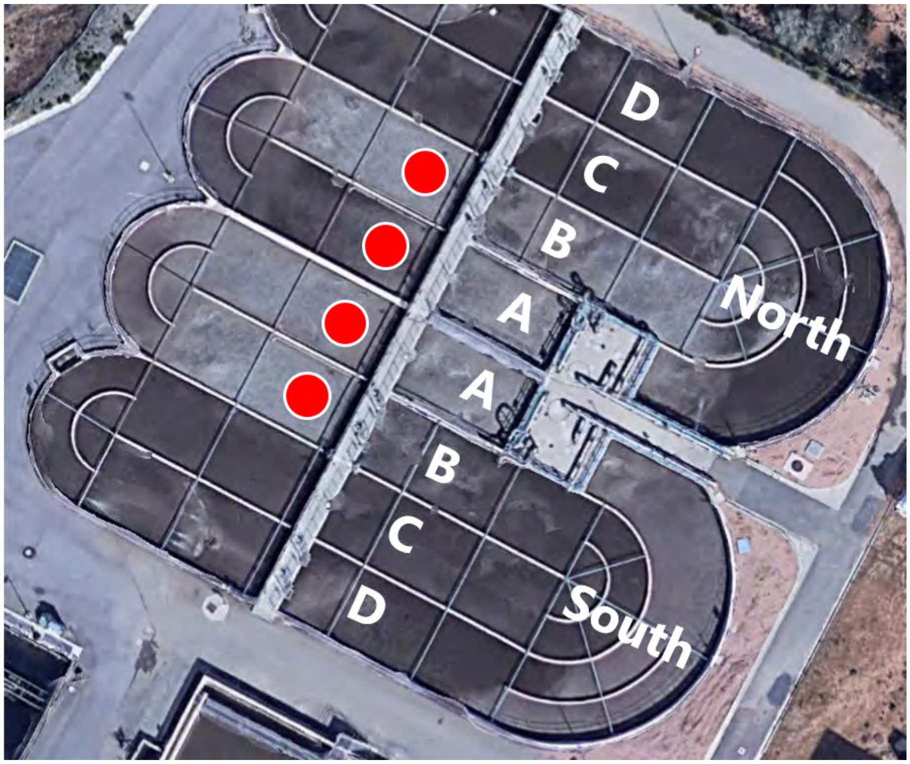

Figure 4.5 DO Sampling Locations in the Aeration Basins

4.2.4 Secondary Influent TKN Load Fluctuations

Another important factor effecting nitrification performance is variability of the TKN load into the secondary treatment process. This load can vary significantly, particularly in facilities with anaerobic digestion. Figure 4.6 shows exemplarily the daily effluent ammonia concentrations for

3 weeks in September and October in 2014. A weekly pattern indicates that NH_4-N concentrations are higher over the weekend and at the beginning of the week, and taper off towards Fridays. This pattern may be influenced by the weekly dewatering schedule, in which case filtrate flow equalization can help to buffer out spikes in effluent ammonia. The current dewatering schedule is to operate one press at night and two during the day. The TKN load should therefore increase early in the morning when the diurnal morning flow has not yet increased.

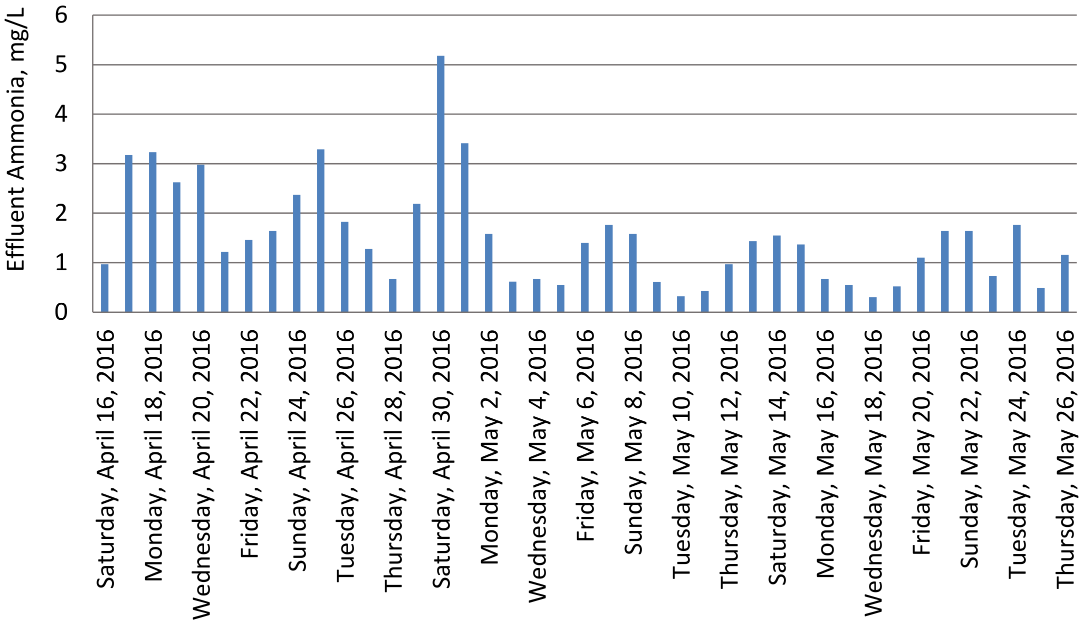

Figure 4.6 Daily Effluent Ammonia Concentrations (September 22-October 19, 2014)

4.3 Nitrogen Removal Performance

Effluent TN is comprised of residual NH_4-N, nitrate, nitrite, and organic nitrogen.

Effluent nitrate and nitrite concentrations have ranged in recent years from about 1 to 4 mg/L with overall effluent TN concentrations of about 4 to 8 mg/L (see Figure 4.1). Effluent nitrate concentrations depend on the efficiency of denitrification. Denitrification is performed by ordinary heterotrophic bacteria that consume organic carbon under anoxic conditions and utilize nitrate as an electron acceptor (the same bacteria will use oxygen as the electron acceptor instead of nitrate if available).

Denitrification is controlled by mainly four process parameters that are discussed in the following sections:

1. Organic carbon availability;
2. Lack of oxygen in the anoxic selector;
3. Sufficient nitrate in the anoxic selector; and
4. Consistent and low DO concentrations to promote reliable SNDN operation.

4.3.1 Organic Carbon Availability

4.3.1.1 Wastewater Influent Organic Carbon

Effluent nitrate in the PR WWTP typically follows a seasonal trend, with higher concentrations in the winter and lowest concentrations achieved in summer (Figure 4.7). Nitrification remained relatively stable throughout the year and did not affect this trend. This seasonal fluctuation in effluent nitrate concentration is typically observed in BNR facilities and is usually caused by seasonal changes in the influent organic carbon composition. With higher temperatures in summer months in the collection system, wastewater carbon is broken down and solubilized to a higher degree (as compared to winter) resulting in a higher proportion of readily available carbon in the anoxic selectors for denitrification. Seasonal variability may also be due in part to the effect of temperature on microbial growth rates. As a compounding factor, aeration control plays a role at the PR WWTP as operations staff typically increases aeration periods in winter months to improve nitrification performance.

The facility conducted a wastewater influent characterization of organic carbon in May 2017, when wastewater temperatures are still relatively low (see Chapter 3). **It is recommended that this sampling be repeated in later summer months in 2018 to assess the seasonal availability of organic carbon in the City's wastewater.**

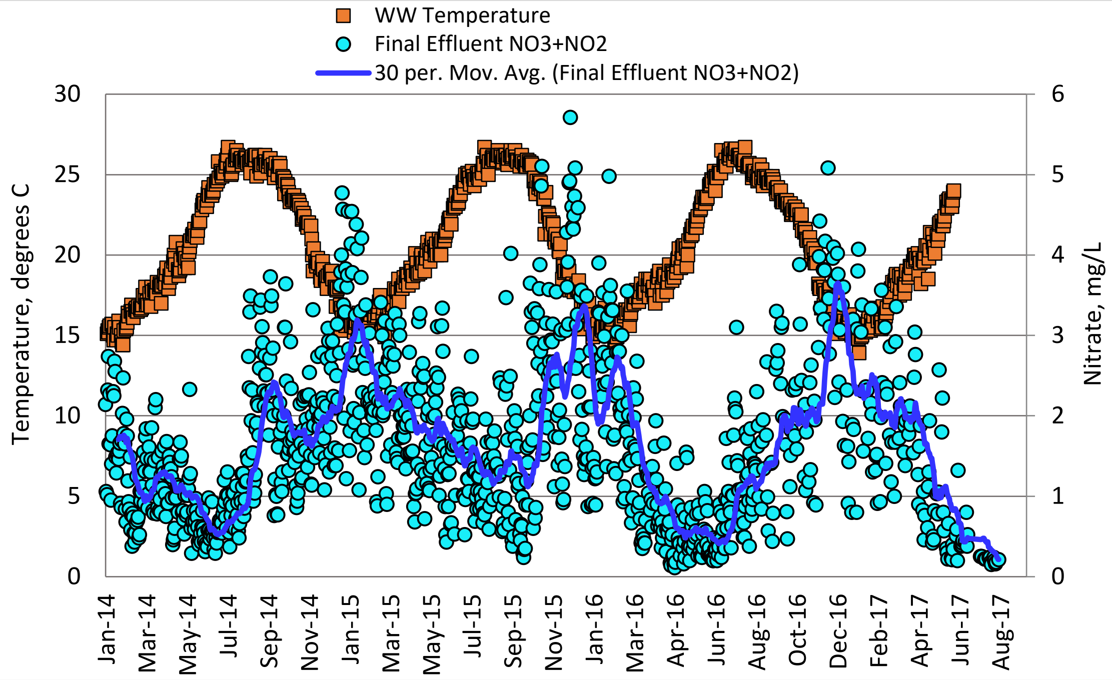

Figure 4.7 Effluent Nitrate versus Wastewater Temperature (2014-2017)

The amount of available carbon for denitrification can be estimated with the carbonaceous biochemical oxygen demand (cBOD) to TKN concentration ratio in the plant influent and aeration basin influent (Figure 4.8). Influent data between July 2014 and July 2016 has been removed as the sampling location was not representative (see earlier discussion). Historical plant data indicate that a cBOD/TKN ratio of about 3 to 5 is typical for the PR WWTP and that this ratio changes little across primary clarification and throughout the year. As a general guideline, a cBOD/TKN ratio above four indicates enough carbon is present to achieve good denitrification performance with typical effluent nitrate concentrations of 10 to 13 mg/L without SNDN operation. The fact that the PR WWTP easily exceeds this benchmark indicates the contribution of SNDN in the treatment process.

However, carbon is likely the limiting factor to further reduce effluent nitrate concentrations below 4 to 6 mg/L (along with better aeration control). In order to consistently achieve effluent concentrations of about 1 mgL, additional carbon will be required and SNDN performance needs to be further improved in the aeration basins. This carbon can be provided either as a purchased chemical or industrial waste product or through internal break down of particulate organic carbon in the liquid or solids process stream. These options are further discussed in Chapter 7.

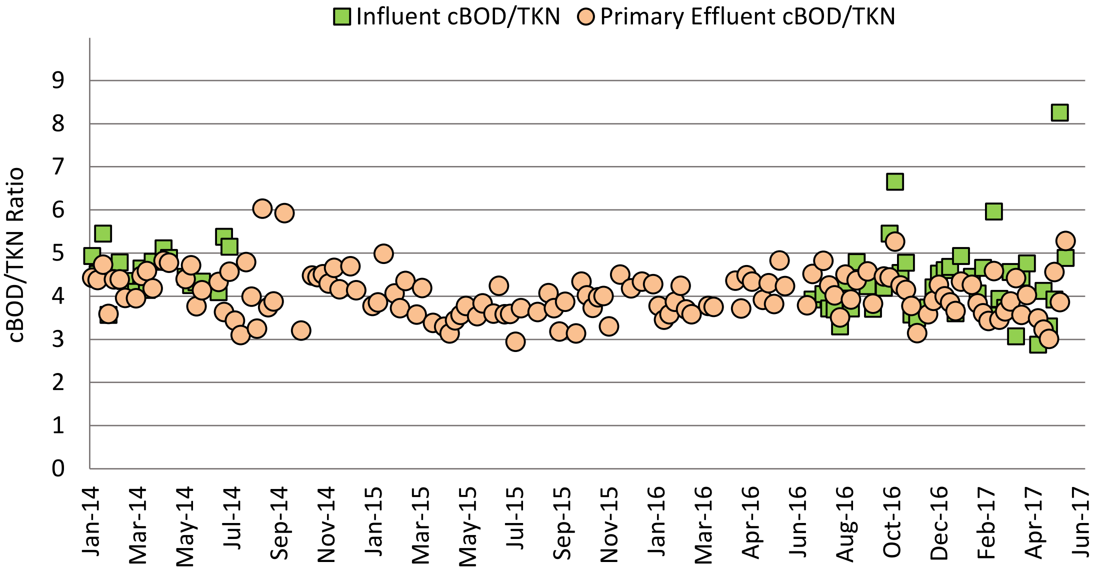

Figure 4.8 Plant Influent and Primary Effluent BOD/TKN Ratio (2014-2017)

4.3.1.2 Primary Clarification

The removal of solids and organic carbon in primary clarification historically has been low and inconsistent. Figures 4.9 and 4.10 show the TSS, cBOD, and BOD removal, respectively, since July 2016. Prior data is not shown as the influent sample location was not representative. During this time, TSS removal varied between 10 and 60 percent. BOD and cBOD removal rarely has exceeded 2 percent.

As discussed in Chapter 3, detailed sampling conducted in May 2017 indicated that the primary clarifiers also do not produce a significant amount of soluble COD in the primary effluent. This is despite operations staff maintaining a sludge blanket, sometimes as high as 6 feet, in the online primary clarifier.

Recommendations for optimizing the primary clarifier operation, which may improve BNR performance, are discussed in Chapter 6.

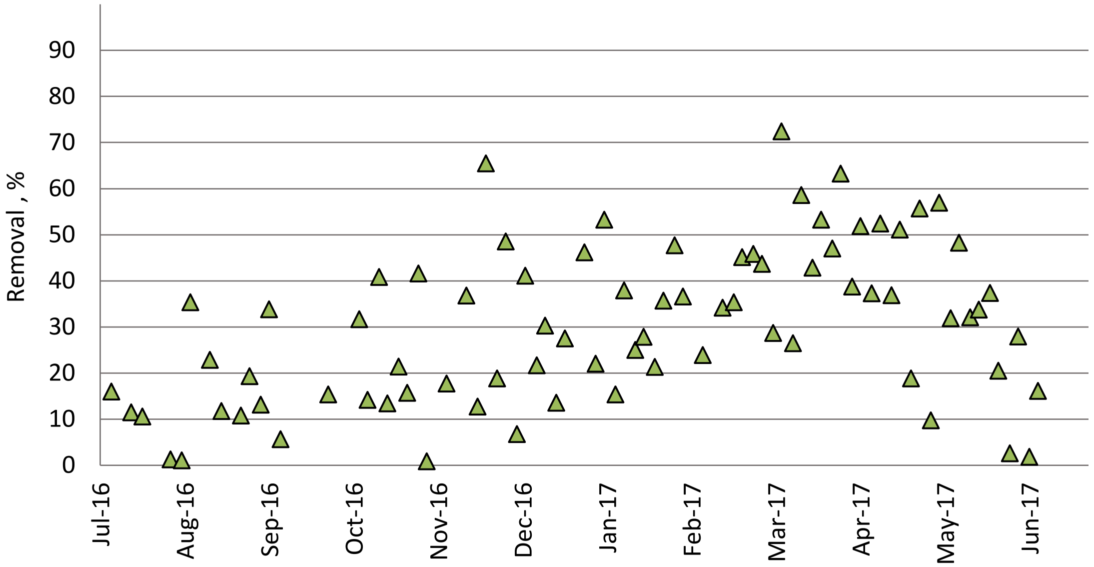

Figure 4.9 TSS Removal in Primary Clarification (July 2016-July 2017)

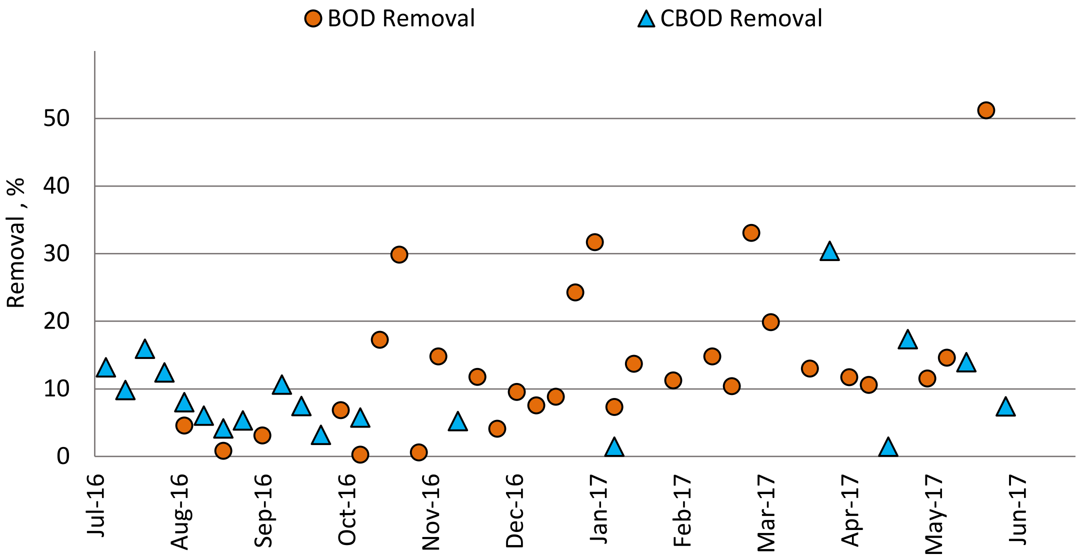

Figure 4.10 BOD and cBOD Removal in Primary Clarification (July 2016-July 2017)

4.3.2 Lack of Oxygen in the Anoxic Selector

The four anoxic bioselectors at the PR WWTP are swing zones that can be operated either as aerated or unaerated. These selectors are typically operated as unaerated unless the facility experiences nitrification performance challenges in the aeration basins due to unreliable blower operation or diffuser aeration system failures. MLR introduced into the bioselectors is recycled from the D Pass of the aeration basins that typically carries very low residual DO concentrations (almost non-detectable). Mixing is accomplished through one paddle mixer per reactor.

Overall, the risk of unintentional oxygen poisoning in the selectors is low if the selectors are not aerated, creating opportune conditions for biological nitrogen and possibly phosphorus removal.

At a combined volume of 1.3 million gallons (MG) and a current average plant influent flow of 5.3 mgd, the total hydraulic residence time (HRT) in the four selectors is almost 6 hours. This is long compared to typical selectors or anoxic zone sizing in other BNR facilities (about 2 to 4 hours). Having additional unaerated volume is an advantage to the PR WWTP and explains why at times the facility has achieved effective orthophosphorus removal. Long retention times in anaerobic zones can also lead to VFA formation, which will improve nitrogen and P removal. Phosphorus accumulating organisms (PAO) will be active in the selectors and release OP when nitrate has been removed to low residual concentrations.

Recommendations for optimization of the anoxic zone (bioselector) operation to improve nitrogen and phosphorus removal are further discussed in Chapter 6.

The PR WWTP operates a significant sludge blanket in the secondary clarifiers on a year-round basis. Figure 4.11 shows the average blanket depths in the six clarifiers that are typically in operation. For spring 2016 and 2017, the data indicate that elevated blanket depths coincide with reduced effluent nitrate concentrations. Other BNR facilities have observed additional N removal in the secondary clarifiers when operating with noticeable blanket depths. Plant staff at the PR WWTP have observed denitrification in the secondary clarifiers when nitrate concentrations in the aeration basin effluent are above about 3 mg/L. Rising sludge, however, has not been an issue in the past. Essentially, the clarifiers serve as a second anoxic zone promoting denitrification under organic breakdown of biomass. This is useful, as long as the facility is able to control diurnal fluctuations in blanket depths or a possible deterioration of sludge volume index (SVI) without running the risk of losing solids over the clarifier weirs. With tertiary filtration, this risk is reduced at the PR WWTP and blanket depth management for additional BNR treatment is a possible operational strategy.

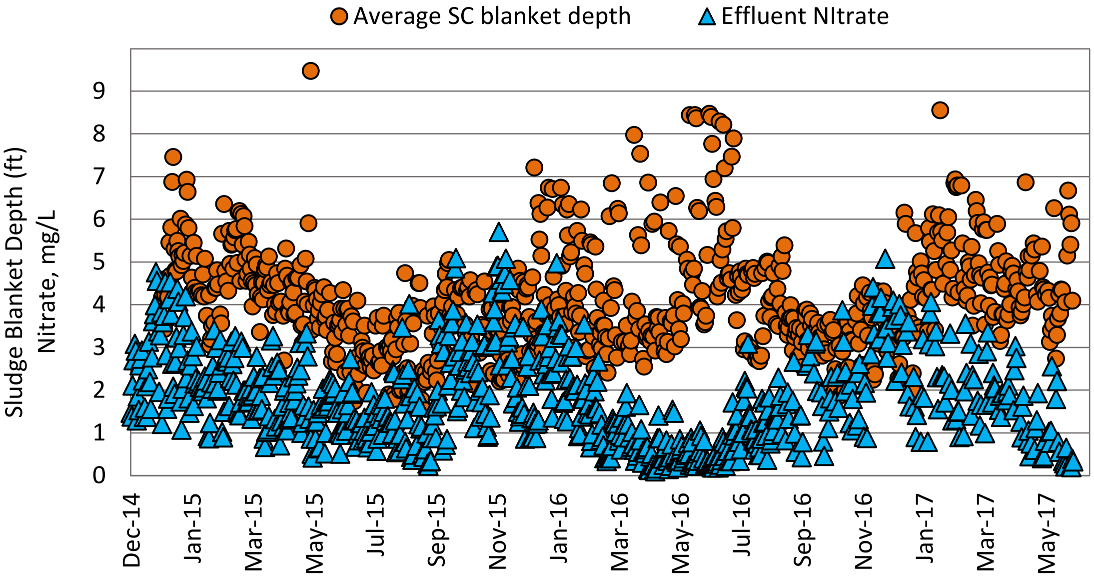

Figure 4.11 Average Secondary Clarifier Sludge Blanket Depth and Effluent Nitrate (2015-2017)

One could suspect that higher blanket levels coincide with poor sludge settling quality; however, this is not the case. The higher blankets in the secondary clarifiers have occurred when SVIs were relatively stable (Figure 4.12). **Thus, the City could evaluate whether to adjust the RAS flows seasonally to maximize the acceptable sludge blanket depths for improved denitrification. It**

is also beneficial to track nitrogen removal across the secondary clarifiers through grab samples or online instrumentation. This would require repair of the VFDs on the RAS pumps to maintain controllable blanket at levels that operations staff is comfortable.

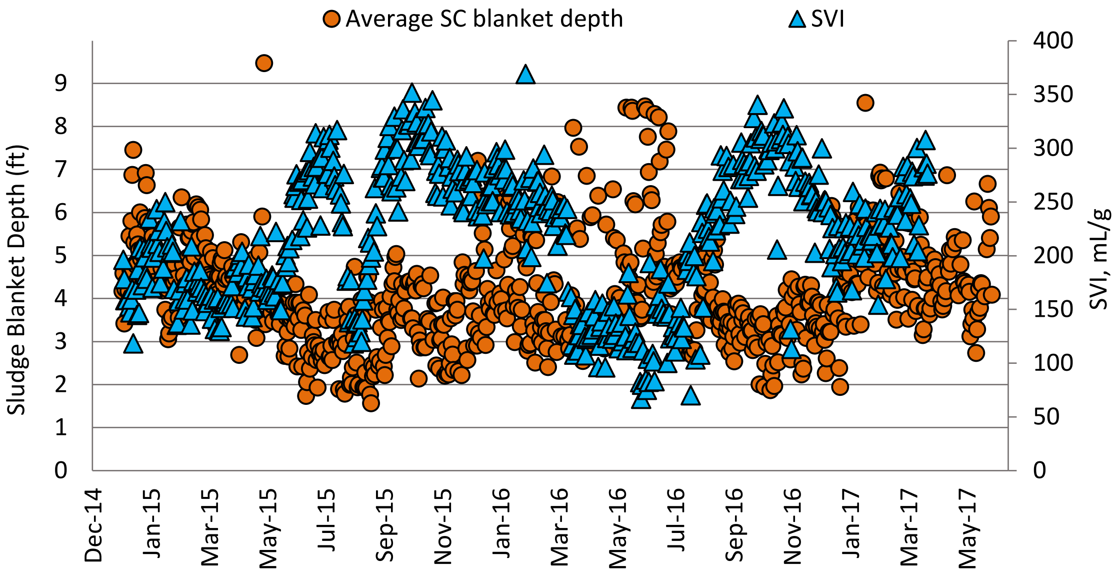

Figure 4.12 Average Secondary Clarifier Sludge Blanket Depth and Effluent Nitrate (2015-2017)

4.3.3 Sufficient Nitrate in the Anoxic Selector

Nitrate is recycled into the bioselector with five available MLR pumps, of which only three units are currently working. Each MLR pump has a constant capacity of 5.04 mgd. In the past, the facility has continuously operated one pump and turned on a second pump during daytime hours. At current average daily flows, this equates to an approximate recycle rate of 100 percent or more with one pump in service and 200 percent with two pumps in service. Since secondary effluent nitrate concentrations are low (ranging from 1 to 4 mg/L) and since the anoxic bioselectors have a long HRT under current flow conditions, it is possible that the selector become nitrate limited. This would be indicated by an effluent nitrate concentration in the selectors of less than approximately 1 mg/L.

An online nitrate probe in this zone can be helpful to assess whether the anoxic bioselectors are optimally used and whether more or less MLR flows would result in additional nutrient removal. If nitrate measured at the end of the anoxic zones are noticeably higher than 1 mg/L during the majority or all of the day, it is likely that MLR flows can be reduced without seeing lower nitrate effluent concentrations in the final effluent keeping assuming all other process parameters stay the same. If the nitrate concentration at the anoxic zone effluent are significantly lower than 1 mg/L during most of the day, the anoxic bioselectors can be limited of nitrate recycle and increased MLR flows may be beneficial to further decrease effluent nitrate concentrations. This only will work if MLR nitrate concentrations are sufficiently high. At MLR nitrate concentrations close to 1 to 2 mg/L, the impact may not be noticeable. However, increasing MLR flows to enhance denitrification in this manner may compromise P removal as the redox potential in the selectors increases and denitrifying heterotrophic bacterial will have a competitive advantage over P-removing bacteria in using up bioavailable carbon.

During the process optimization task described in Chapter 6, additional data was collected to assess how best to improve the efficiency of the bioselectors for BNR treatment in the future.

4.3.4 Effluent Organic Nitrogen

The composition of effluent organic nitrogen and its bioavailability after discharge in the aquatic environment is not yet completely understood and a question of ongoing debate. Organic nitrogen can include diverse compounds such as proteins, amino acids, urea, amino sugars, and humic substances. Proteins are considered to be one major group of effluent organic nitrogen and include recalcitrant (not biologically active in receiving waters) proteins already present in the primary influent as well as soluble microbial products (SMP) that are biologically formed during the biological secondary treatment process. Effluent organic nitrogen contains a soluble and particulate fraction. The site-specific distribution of these two fractions or its components at the PR WWTP has not been further evaluated to date. Average effluent concentrations at the PR WWTP are significant (about 1.8 mg/L) with a rising trend as well as some indication of seasonal variation (Figure 4.13). As plant staff succeeds in further reducing effluent inorganic nitrogen in the future (ammonia, nitrite, and nitrate), the effluent organic nitrogen fraction will become increasingly important in the facility's ability to lower effluent TN concentrations.

The soluble portion of effluent organic nitrogen has been found to contain a large refractory fraction and a smaller group of degradable compounds such as amino acids and urea. However, a large portion of dissolved organic nitrogen is not identifiable with today's analytical methods we are limited to characterize this portion in terms of its overall molecular size distribution, hydrophobicity, and simulated degradability through bioassays.

Another area that is not yet well understood is which processes drive organic nitrogen levels in treated effluents. A better understanding here will help facilities and engineers to tailor process design and treatment operation to minimize organic nitrogen concentrations further in treated effluents. It has been hypothesized that primary clarification and anaerobic digestion as well as secondary treatment operation play a role. Tertiary media filtration and advanced secondary treatment have been found to reduce effluent organic nitrogen. It is therefore likely that the recycle stream management at the PR WWTP (specifically dewatering filtrate and filter backwash) play a role in effluent organic nitrogen concentrations.

Historical plant data for the PR WWTP indicates a seasonal fluctuation in effluent organic nitrogen, with highest concentrations typically occurring in late winter/early spring and lowest concentrations in the fall. The trend is clearly anti-proportionate to the wastewater temperature. Also, the average effluent organic nitrogen concentrations have been increasing over the recent three years. It is possible that water conservation efforts in the City's service area, and the increased wastewater influent strength as a result thereof, also have contributed to the increased concentrations of effluent organic nitrogen.

Recommendations for further evaluation and possible reduction of effluent organic nitrogen at the PR WWTP are discussed further in Chapter 6.

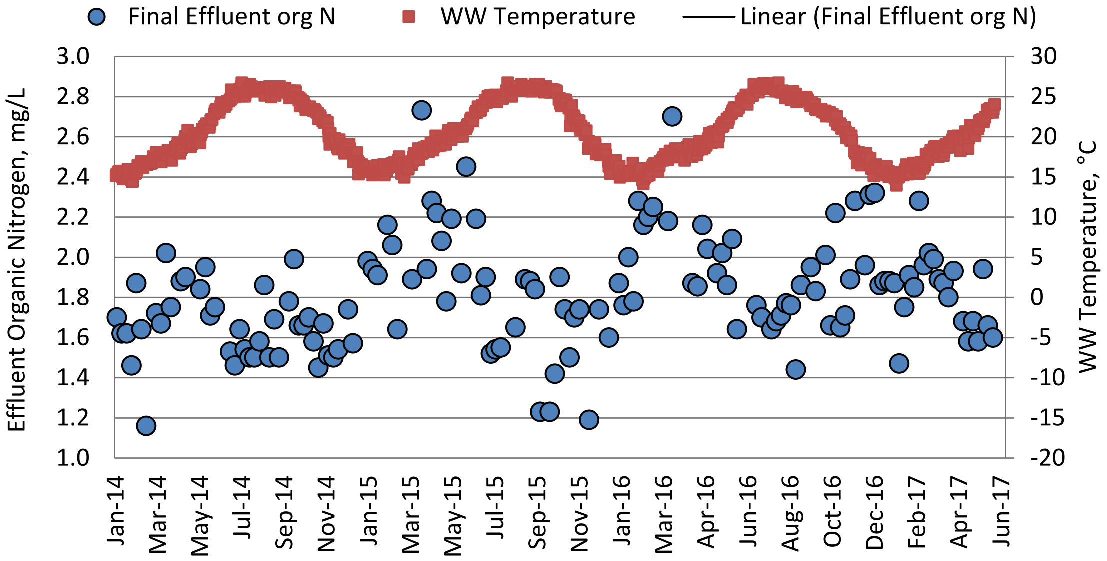

Figure 4.13 Effluent Organic Nitrogen and Wastewater Temperature (2014-2017)

4.4 Phosphorus Removal Performance

Phosphorus is present in influent wastewater in particulate and soluble form. Soluble P must first be converted into particulate form before it can be removed through settling or filtration. This can occur by either chemical precipitation or uptake into the biomass (enhanced biological phosphorus removal [EBPR]). The PR WWTP is currently not designed for biological P removal. The facility has anoxic selector zones receiving MLR, but not an explicit anaerobic selector zone. Regardless, biological P removal has been observed at times when very low nitrate concentrations are achieved in the secondary treatment.

Figure 4.12 shows the historical total and OP concentrations in the final plant effluent since 2014. Periods with good EBPR (OP less than 1 mg/L) have been indicated in the figure. During these periods, not only is OP low, there is also very little particulate P present in the effluent. Typically, particulate P removal in the clarifiers and cloth filters is efficient. Only on two occasions did the facility experience elevated particulate P concentrations in the final effluent (January to May 2014 and August to December 2016). The effluent spike in particulate phosphorus in 2016 was caused by an effort to empty the sludge-holding tank.

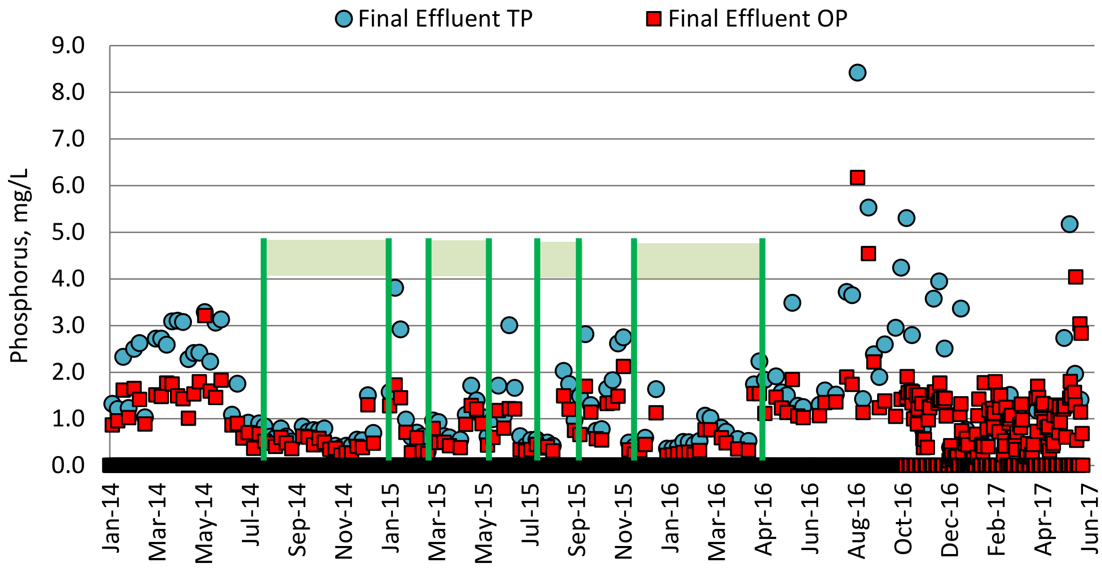

Figure 4.14 Effluent Phosphorus Concentrations (2014-2017)

Typically, solids remove in the secondary clarifiers and tertiary filters is very good, achieving effluent TSS concentrations of less than 5 mg/L (Figure 4.15). Therefore, the optimization of P removal should focus on OP removal through EBPR as further discussed in Chapter 6.

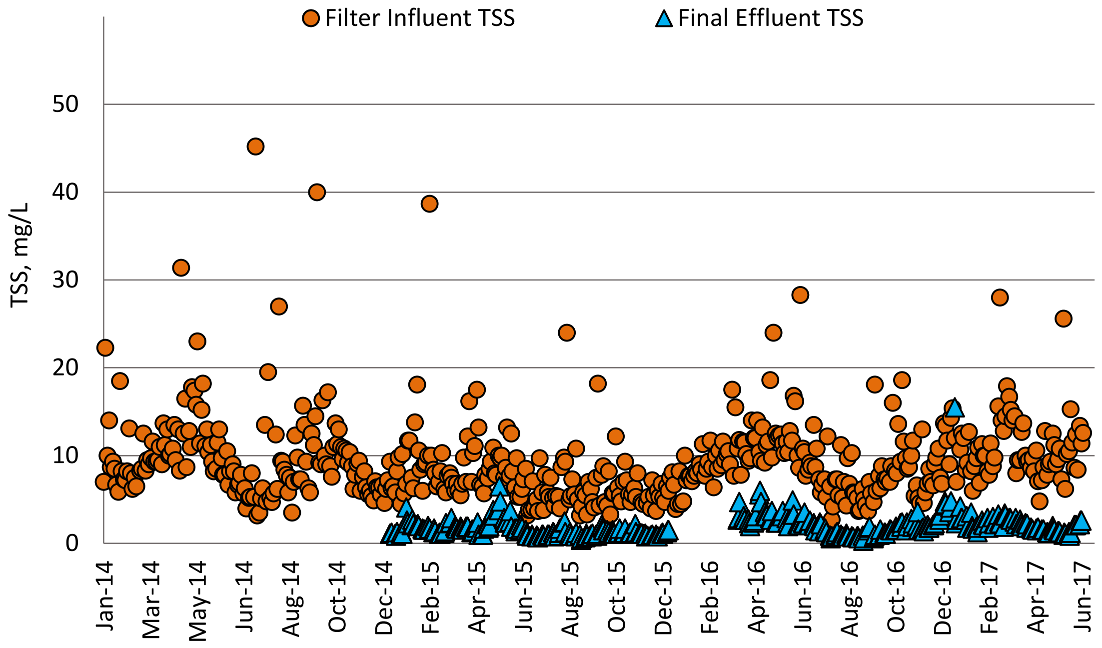

Figure 4.15 Secondary and Tertiary Effluent TSS (2014-2017)

4.5 Nutrient Profile Testing Results

A profile test was conducted in the secondary treatment process on June 16, 2017 in order to better understand the existing nutrient removal efficiency before operational optimization tests were initiated in the second part of 2017. Figure 4.16 shows the sampling locations that were included in this sampling campaign. Grab samples were collected from the following nine locations:

1. Aeration Basin Influent - Bioselector influent (splitter box),
2. ANX 1 - Anoxic Zone 1 effluent (end of first bioselector),
3. ANX 2 - Anoxic Zone 2 effluent (end of second bioselector),
4. SA - South Aeration Basin - A Pass (from bridge),
5. SB - South Aeration Basin - B Pass (from bridge),
6. SC - South Aeration Basin - C Pass (from bridge),
7. SD1 - South Aeration Basin - D Pass (from bridge),
8. SD2 - South Aeration Basin - D Pass (close to MLR location at east end), and
9. SE - Combined secondary clarifier effluent drop box.

The samples were analyzed for NH_4-N, nitrate, OP, DO, oxidation-reduction potential (ORP).

Figure 4.16 Profile Testing Sampling Locations (June 16, 2017)

Sample collection was conducted between 10 and 11 a.m., when influent flows were about 4 mgd and had not yet reached the afternoon peak (Figure 4.17). Because of this, it was anticipated that the absolute concentrations measured during the profile sampling campaign would be below the concentrations measured by the laboratory on the same day for the composite effluent samples.

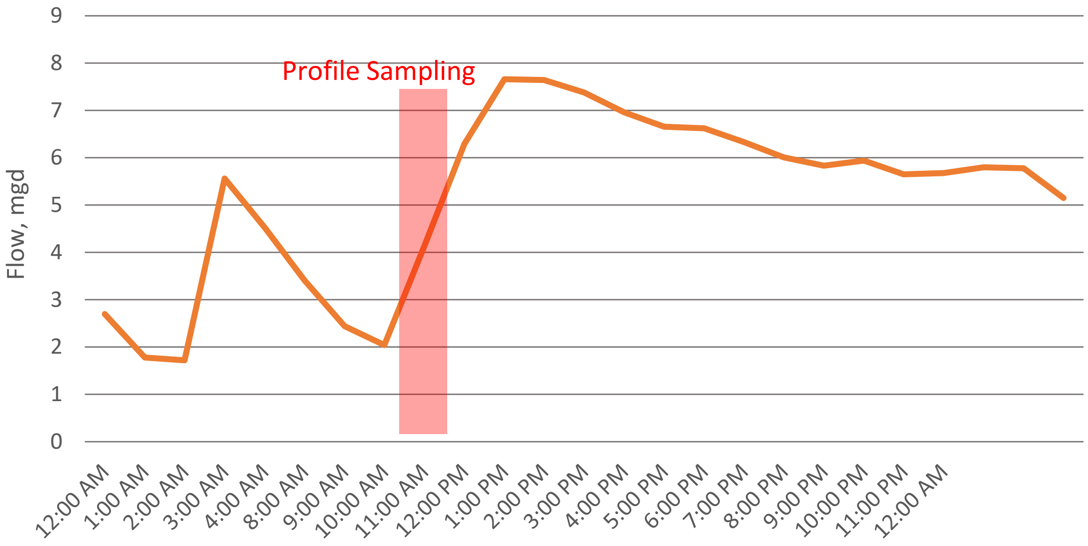

Figure 4.17 Diurnal Influent Flow Profile (June 16, 2017)

The DO and ORP profile through the secondary treatment system is shown in Figure 4.18. DO was about 1 to 1.5 mg/L in the aerated A and B Passes of the basins. The secondary effluent contained 2 mg/L DO despite the fact that the C Pass from which mixed liquor is wasted is not aerated. DO concentrations were almost non-detectable in the bioselectors and the C and D Passes.

The ORP was measured below -200 millivolts (mV) in the anoxic bioselectors and at the end of SD-2, indicating good redox conditions for nitrate removal and EBPR.

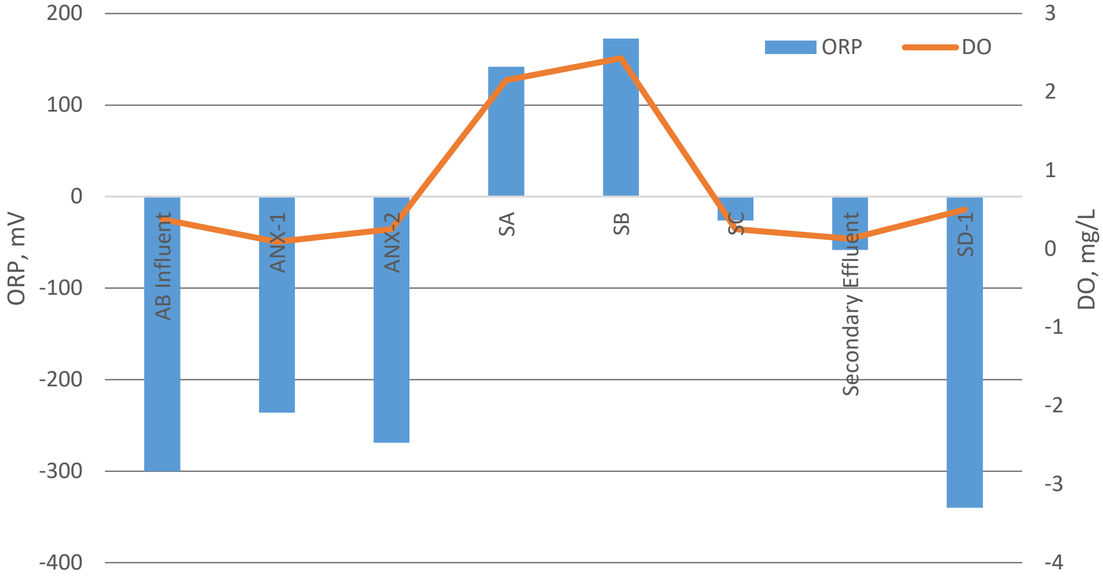

Figure 4.18 Secondary Treatment DO and ORP Profile (June 16, 2017)

The NH_4-N concentration profile revealed that nitrification performance was essentially completed in the A Pass and aeration in the B Pass was essentially unnecessary (NH_4-N profiles had already dropped well below 1 mg/L) (Figure 4.19). The ammonia concentration at the end of the D pass increased significantly, which was caused by the introduction of aeration basin influent. For the month of June 2017, the average NH_4-N concentration typically ranged between 1 and 3 mg/L in the secondary effluent. The horizontal velocity of the wastewater through the basin was not determined in this study. In some oxidation basins, this velocity is high enough to cause essentially lateral mixing such that horizontal nutrient profiles are flat due to mixed conditions. Whether this is the case in PR WWTP's system should be further investigated through additional profile sampling under different performance conditions.

The nitrate concentration profile was equally interesting in that none of the grab samples contained significant amounts of nitrate. The effluent nitrate and nitrite concentrations for the month of June 2017 were very low and were typically below 0.8 mg/L. Because of very little nitrate in the secondary effluent, hardly any nitrate was recycled into the anoxic bioselectors, which were therefore de facto anaerobic selectors. It was therefore not surprising that P was removed very well during this sampling campaign. The nitrate profile indicated that one, if not both, of the MLR pumps could have been turned off during the sampling campaign with little change in the effluent quality.

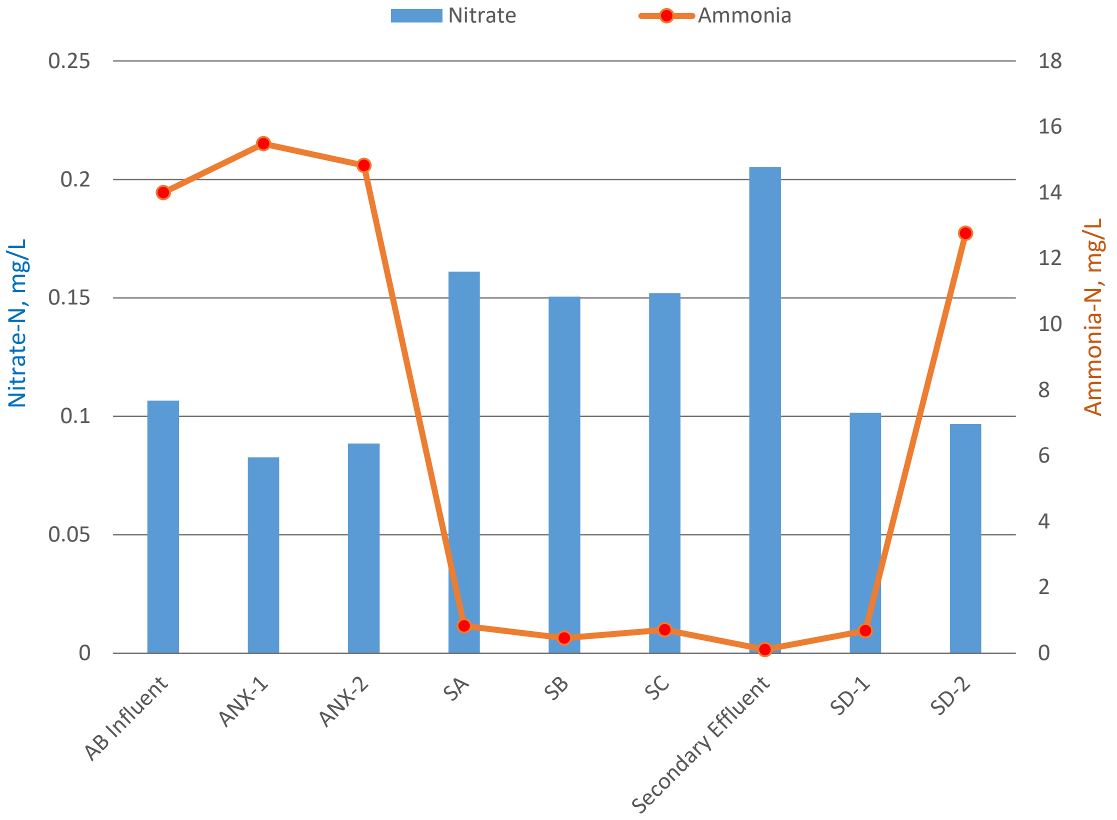

Figure 4.19 Secondary Treatment Nitrate and Ammonia Profile (June 16, 2017)

The OP concentrations in the secondary treatment system demonstrate the classical profile for effective EBPR (Figure 4.20). Very high P concentrations are observed in the bioselectors due to P release by PAOs. OP is then quickly taken up in the aerobic zones and gradually drops below 1 mg/L in the effluent of the aeration basin (end of C Pass). The effluent TP concentrations for the month of June 2017 ranged between 0.5 and 1.7 mg/L. It is possible that the OP concentrations at the end of the D Pass were again higher because of of the influence of aeration basin influent.

There were, however, a few inconsistencies with this data set as briefly mentioned in the following:

- The aeration basin influent OP concentration was expected to be lower. It is recommended to measure filtrate recycle flows and phosphorus concentrations to complete the mass balance when profile testing is repeated.
- Future testing should verify whether OP concentrations in the C and D Passes indeed increase (i.e., as a result of secondary P release) or if this was an artifact of sample collection and preparation.

It is recommended that facility staff repeats this profile testing in the South and North Trains in the future and at different times (good or poor BNR performance, peak daily loading conditions, different seasonal conditions, weekend vs. weekday, etc.) to better understand the effectiveness of each treatment zone for NH_4-N, nitrate and P removal. Profile test results allow informed decisions on how to modify treatment operations to optimize nutrient removal.

It is further recommended to conduct at times of poor EBPR performance a microscopic evaluation of the activated sludge to assess whether glucose accumulating organisms (GAO) proliferate in the activated sludge, which can complete with PAOs for the same carbon sources and do not remove phosphorus. This bacteria are not uncommon in warm weather BNR treatment systems with long sludge ages.

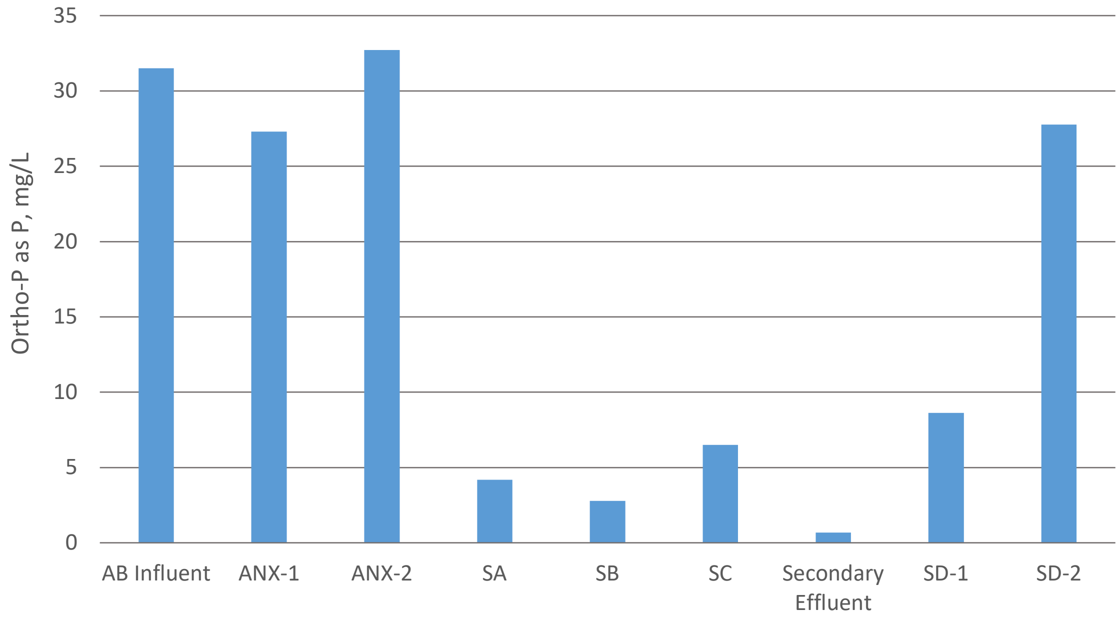

Figure 4.20 Secondary Treatment Ortho-Phosphorus Profile (June 16, 2017)

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Chapter 5

PROCESS MODELING AND CAPACITY EVALUATION

5.1 Purpose

This chapter describes the process modeling approach and model calibration. The calibrated process model was used to assess the secondary treatment capacity of the existing facility. It was further used to assess possible process optimization strategies as described in Chapter 6.

5.2 Process Model Calibration

5.2.1 Calibration Period and Model Inputs

Historical process data between January 2014 and June 2017 was analyzed to identify an appropriate period for process model calibration (see Chapters 3 and 4). As discussed, wastewater influent data prior to August 2016 was not representative due to the influent sampling location used at that time. Therefore, the process model calibration was based on the period between August 15, 2016 and June 15, 2017. A BioWin model was calibrated as a dynamic model for the liquid process stream based on daily plant influent data for influent flows, COD, TKN, NH_4-N, TP, and OP. The plant influent included filtrate recycle from dewatering including washwater. Other process model inputs included the physical dimensions of the primary and secondary treatment processes in operation during the calibration period, as well as the daily primary and secondary waste flows, DO concentrations, and RAS flows.

Occasionally, the plant influent TKN, TP, and COD concentrations needed to be adjusted as the mass balance of the reported constituent concentrations in the influent produced errors. In these cases, either the TKN and TP concentrations needed to be increased or the COD concentrations needed to be decreased in order to close the constituent mass balance. The adjustment was made to remain consistent with the recorded influent concentrations for TKN, TP, and COD before and after the specific data points in question. No other adjustments needed to be made to the modeling inputs for model calibration.

5.2.2 Process Model Calibration Summary

Appendix A includes the modeling report of the process calibration run. A very good match was achieved between the influent CBOD, TSS, and VSS concentrations that were calculated by the process model based on the actual COD plant data and fractionation.

The aeration basin influent concentrations for CBOD and TSS also match the actual plant data very well. This is relevant to adequately model the nutrient removal process and treatment capacity in the secondary treatment process.

The MLSS concentrations closely matched the reported plant data for the most part. However, between September 2016 and March 2017, the model over predicted the MLSS concentrations in the aeration basins. It is possible that the influent composition during this period varied from the rest of the calibration period.

The calibrated model matched the partial nitrification that the plant experienced throughout the year well (see figures in Appendix A). Denitrification also was very closely predicted and the modeled effluent TN concentration was within typical concentrations of 5 to 7 mg/L. Effluent OP and TP concentrations were adequately predicted and so was the occasional loss of biological P removal.

The calibration was achieved by changing two kinetic parameters. The maximum specific growth rate of the PAOs was reduced to match the lower effluent OP concentrations observed in the plant. Secondly, the DO half saturation constant for heterotrophic bacteria was increased to calibrate the model to the SNDN in the aeration basins under low DO concentrations. Without this adjustment, the model would not be able to predict the low effluent nitrate concentrations the facility observes. It was assumed that no biological processes take place in the primary or secondary clarifiers.

Table 5.1 summarizes the averages of model predicted parameters throughout the calibration period in comparison to the actual plant data averages. The deviations are generally less than 10 percent, which indicates a very good, industry-accepted calibration standard. Effluent nitrate and nitrite, TN, and effluent TSS have slightly higher errors and the model predicts slightly less nitrogen removal than observed in the facility. (As the numeric values for nutrient removal become lower, the error between model prediction and real plant data is prone to increase.) One reason for the under prediction of denitrification could be additional denitrification occurring in the secondary clarifiers that the model was not calibrated to predict.

Table 5.1 Comparison of Process Model Calibration (August 15, 2016-June 15, 2017)

Parameter	Average Process Model Simulation	Plant Data Average	Deviation
Influent CBOD, mg/L	387	351	9.3%
Influent TSS, mg/L	390	370	5.1%
MLSS, mg/L	2,803	2,540	9.4%
WAS Solids, ppd	12,580	12,560	0.2%
Effluent Ammonia, mg/L	2.1	2.1	0%
Effluent Nitrate + Nitrite, mg/L	2.2	1.9	13.6%
Effluent TN, mg/L	7.0	5.9	15.7%
Effluent TP, mg/L	1.2	2.0 1.6 since Jan 2017	38% since Jan 2017
Effluent TSS, mg/L	9.1	11.7	28%

Notes:

MLSS	mixed liquor suspended solids	ppd	pounds per day

The model does not simulate the breakthrough of particulate P that the plant has frequently observed in 2016 and occasionally also in 2017. As a consequence, the model under predicts P concentrations in the final effluent compared to the actual plant data. However, the model predicts P removal well during periods without effluent P spikes.

5.2.3 Process Model Data Gaps and Recommendations

The process model calibration identified some uncertainties and gaps in the existing plant process data that would be helpful to address in order to further refine process modeling efforts for future design purposes. It is recommended to collect the following process data in the future:

1. OP and TP concentrations in the secondary effluent (filter influent) to verify final effluent concentrations (i.e., sometimes the data indicate that TP in the secondary effluent is less than OP in the final effluent).
2. Diurnal DO profiles in the aeration basins throughout the seasons for more accurate process modeling. (This was subsequently implemented by installing DO probes in several zones in both basins.)
3. Conduct frequent TSS and COD mass balances around the primary clarifiers to verify clarification performance, data reliability, and the effectiveness of in-situ fermentation.
4. Characterize the filtrate recycle streams periodically in the future.
5. Conduct influent sampling without filtrate periodically in the future (if sampling can be made possible) to help define the actual strength of the incoming domestic wastewater.
6. Consider a TSS analyzer for MLSS monitoring in the aeration basins to track the operating SRT better.

5.3 Primary and Secondary Treatment Capacity Evaluation

The calibrated process model was subsequently used to verify the design capacity of the PR WWTP at 13 mgd ADMMF assuming that the current wastewater influent strength will remain comparable in future years, and that all units are in service. The capacity evaluation was conducted for the primary and secondary treatment processes only. Table 5.2 summarizes the projected process criteria at a treatment of 13 mgd ADMMF for primary and secondary treatment.

Table 5.2 Summary of Treatment Criteria at a Capacity of 13 mgd ADMMF

Process	Unit	Projected at 13 mgd ADMMF	Recommended Design Value
Primary Treatment			
Surface Overflow Rate @ ADMMF	gpd/sq ft	937	800-1,200
Aeration Basins			
HRT (Bioselectors)	hours	2.4	0.5-1 hour anaerobic 1-3 hours anoxic
HRT (Aeration Basins)	hours	12	NA
tSRT	days	10	Minimum recommended SRT
MLSS	mg/L	7,100	3,000-4,000
Secondary Clarification			
Surface Overflow Rate @ 100% RAS	gpd/sq ft	796	600-700
Solids Loading Rate (SLR)	ppd/sq ft	47	25-30

The primary treatment capacity is sufficient for the current hydraulic capacity rating. However, the secondary treatment capacity is insufficient to treat 13 mgd ADMMF at the current influent concentrations. At a minimum SRT of 10 days (the facility actually typically operates above this value in winter), the MLSS concentration and the SLR on the secondary clarifiers far exceed recommended design guidelines (Table 5.2). This is not surprising as significant water conservation efforts have been implemented over the past years in the City's service area. This has resulted in lower per capita wastewater flows but higher wastewater influent concentrations. Therefore, the projected wastewater influent load exceeds at 13 ADMMF the original design load of the PR WWTP.

Process modeling predicts that the aeration basins can be operated at around 7.5 mgd ADMMF at an SRT of 10 days with a MLSS concentration of about 4,000 mg/L. Additional secondary treatment capacity could be gained by increasing the biochemical oxygen demand (BOD) and TSS removal efficiency in the primary clarifiers in the future (see discussion in Chapter 4).

The facility may be able to carry higher MLSS concentrations than 4,000 mg/L in the aeration basins while still providing reliable treatment and high sludge quality. This should be further evaluated in future master planning efforts. It is further recommended to investigate anticipated future flows and loads in more detail when undertaking any aeration system upgrades or modifications in the near future to assure that the system will be designed for realistic design flows and loads.

The current process air demand was estimated based on aeration data provided between January and February 2018 when the wastewater temperatures were as low as 15 degrees Celsius. The maximum aeration rate for both aeration basins was 5,300 scfm, which would generally occur late afternoon to early evening. Usually, this maximum air demand was achieved with two blowers in operation at about 65 percent of maximum air flow capacity, each.

The current ADAF is about 5.3 mgd. Estimating the design air demand at 8.5 mgd ADMMF (which is the 20-year projected flow) proportionately from this current air demand (assuming influent concentrations remain constant), results in an estimated future design air demand of about 8,500 scfm. Adding an additional 30 percent capacity to accommodate peak air demands throughout the year results in a firm recommended blower capacity of about 11,000 scfm. This projected air demand was used in Chapter 7 to estimate the capital costs for replacement of the existing turbo blowers. It is recommended to revisit the required future aeration capacity in more detail in a future project as a more thorough analysis of future air demands was outside of the scope of this study. This should entail an evaluation of projected influent flows and loads during the upcoming planning period, load peaking factors, the recommended diffuser layout to meet future nutrient treatment goals, options for firm and redundant blower capacity with blower units currently in place and their present condition, as well as air demand calculations based on the recent oxygen transfer evaluations conducted as part of this study (see Chapter 6).

Chapter 6

PROCESS OPTIMIZATION AND CONTROL

This chapter describes the identified options for optimization of the existing liquid stream treatment process to reduce N and P effluent concentrations. Two optimization opportunities were selected by the staff to be tested during this study starting in August 2017. The testing approaches and results to date are summarized herein as well.

Since 2017, the City is in the second year of a 3-year compliance schedule, meaning that the tight nutrient limits in the current permit (see Chapter 2) for N and P do not have to be met yet (with the exception of a TN limit of 10 mg/L, which must be met currently). Therefore, the City determined that 2017 and 2018 will be an opportune time for optimization testing. It is anticipated these efforts will be continued beyond the completion of this study.

As a benchmark, PR WWTP management set forth ambitious effluent concentration targets as goals for the process optimization, a TN of 3 mg/L and a TP of 0.3 mg/L on a maximum month basis. The optimization testing conducted by plant staff during this study was valuable in demonstrating the facility’s ability to approach these effluent targets and the additional improvements that will be necessary to achieve and maintain them.

6.1 Overview of Optimization Opportunities

Several optimization opportunities for improving nutrient removal were identified for the PR WWTP based on the detailed historical process performance analysis summarized in Chapter 4. In addition, operational strategies were considered that are in place at other BNR facilities that achieve very low effluent nutrient limits and have a comparable process configuration. The optimization strategies were grouped into three steps that are building onto each other:

1. NH_4-N removal.
2. N removal (denitrification).
3. P removal.

Nitrification optimization is the first necessary step, as any N that remains in the form of NH_4-N in the effluent cannot be biologically removed in the existing treatment process. Optimizing denitrification is the second necessary emphasis as any remaining nitrate in the secondary effluent is recycled as mixed liquor and RAS and diminishes the effectiveness of biological P) removal. Once NH_4-N and N removal are optimized, efforts can focus on optimizing P removal.

While the following sections describe optimization opportunities separately for each of these three steps, it should be recognized that nitrification, denitrification, and P removal are tightly interconnected in the biological treatment system and individual treatment changes will have effects on multiple effluent parameters.

6.1.1 Nitrification Optimization

6.1.1.1 Solids Inventory Control

Rapid changes in solids inventory carried in the aeration basins must be avoided in order to avoid effluent breakthrough of NH_4-N. Historically, the facility staff maintains very stable MLSS concentrations. Wasting is currently based off gallons of WAS. While this has been an acceptable approach in the past, **it is recommended to consider introducing the following changes into future standard operating procedures:**

1. In addition to gallons wasted, track pounds of solids wasted and pounds of solids carried in the aeration basins on a daily basis.
2. Track aerated solids inventory separately from total inventory carried in the system using the following equation.

$$SRT_{aer} = \frac{V_{aer} * MLSS}{Q_{WAS} * TSS_{WAS} + Q_{eff} * TSS_{eff}}$$

3. Assess appropriate plant specific DO concentration boundaries for defining solids inventory as "aerated" (e.g., all solids inventory at a DO concentration at or above 0.5 mg/L is counted as aerobic). Define the minimum required aSRT by wastewater temperature and season that guarantees full nitrification specific to this facility. Define adequate safety factors for the minimum aSRT. Unnecessarily high solids inventory increases the growth of some filaments and may limit aeration basin treatment capacity prematurely in the future. Inventory that is too low increases the risk of NH_4-N breakthrough, especially during process upset conditions.
4. Establish standard operating procedures for maintaining stable aerobic and total solids inventory when taking one aeration basin out of service to prevent temporary NH_4-N effluent breakthrough.

6.1.1.2 Aeration Control

Over the past years, plant staff has evaluated alternative aeration strategies to lower effluent N. These efforts included testing different DO setpoints and aeration of different diffuser grids and basin passes. Building on this past experience, **the following recommendations were developed for future aeration optimization:**

1. Determine what minimum DO setpoints will be sufficient to achieve full nitrification. Make changes in DO setpoints in small increments.
2. Implement automated DO control in the future and automate the air valves to all diffuser grids. This will allow plant staff to refine further aeration control throughout the day and opens up additional optimization opportunities. This includes intermittent aeration of specific zones to promote SNDN operation and controlling air flows or DO setpoints based on online water quality monitoring (e.g., NH_4-N or nitrate based DO control, ORP based DO control, or combinations thereof).
3. Consider alternating aerated and unaerated diffuser grids throughout the passes to improve SNDN operation.
4. Document future aeration optimization tests, not only on hard copies, but also in electronic form. Document rationale for changing target DO setpoints and anticipated performance changes in advance of any testing. Plot actual test results in graphical form and include resulting effluent quality changes. This is important to communicate targeted operational strategies among plant staff and all shift operators in advance and

during optimization testing. It also documents test approaches and results for future reference.

5. Target full nitrification first (effluent NH_4-N below 0.5 mg/L). Then optimize effluent total inorganic nitrogen (TIN) by trimming nitrate while maintaining full nitrification.
6. Install online DO probes in both aeration basins and in relevant aerated zones to monitor DO profiles in the aeration basins continuously. Relocate the probes in the basins as needed to gain a comprehensive overview of DO profiles throughout all passes.
7. Install NH_4-N probes in both basins and determine the best location to inform required upstream and/or downstream DO setpoint adjustments.
8. Monitor the process for possible NH_4-N generation in extended unaerated aeration basin zones (e.g., the C and D Passes). It is possible that ammonification (the decomposition of organically bound N in biomass cells) can occur that increases NH_4-N in the basin effluent. This can be tracked and avoided through additional profile testing.
9. Consider the current minimum process air demand when upgrading blowers and replacing diffuser grids in the future to avoid having to over-aerate.
10. Periodically conduct profile testing throughout all aeration basin zones for N (and P) species under different aeration patterns to better match air supply to the actual air demand in different passes in the basins.

During the winter of 2017/2018, plant staff began to implement and test some of these recommendations to lower effluent NH_4-N concentrations. These efforts and results are summarized in Section 6.5.

6.1.1.3 Surface Wasting

Surface wasting is another tool that can be used to improve performance by wasting solids preferentially from the surface of the aeration basins. This can control the growth of filamentous bacteria, which can proliferate on the surface of aerated zones. Surface wasting also removes scum that may build up on the surface.

Surface wasting can be performed a number of ways, including via a rotating weir located across the surface of the aeration basins, or a downward opening weir gate located on to the side of the flow path. The solids wasted from the surface of the aeration basin are combined with the solids wasted from the RAS flow, and the total pounds wasted from both systems controls the SRT.

6.1.1.4 Dewatering and Sidestream Management

Special sampling conducted during this study in May 2017 identified that filtrate recycle from the belt filter presses can contain significant TKN recycle loads. During two week sampling campaign, TKN dewatering recycle loads varied between 2 and 14 percent of the TKN influent load (see Chapter 3). TKN recycled from dewatering consists mainly of NH_4-N and is not removed in primary clarification. Dewatering recycle streams also affect P effluent concentrations as discussed further below. Because varying NH_4-N load to the secondary treatment process can strain the nitrification process, **consideration of the following modifications is recommended in the future:**

1. Installation of a flow meter on the filtrate recycle pipe routed to the headworks. Plant staff included this flow meter as a change order in the ongoing digester improvements project for installation in 2018.

2. Frequent monitoring of filtrate recycle water quality. Because the recycle water quality varies significantly on a daily basis, it is recommended to collect a larger database to adequately characterize this plant internal process stream. Most important monitoring parameters are TP, OP, TKN, and NH_4-N. TSS and COD can be monitored at lesser frequency as these concentrations were generally in acceptable ranges and less variable. This data is relevant for operations staff today to understand and explain variability in effluent nutrient concentrations. It will also be relevant in the future to further assess the cost-effectiveness of sidestream treatment processes, as well as for process selection and design.
3. Detailed evaluation of current dewatering practices and optimization potential. The current practice of dewatering two different solid streams alternatively on the belt filter presses throughout the week (with and without lime stabilization) is labor intensive and makes it difficult to optimize dewatering efficiency. This practice also contributes to the variability of filtrate recycle quality and nutrient loads.
4. Consider future implementation of filtrate flow equalization and sidestream treatment. Filtrate flow equalization will help to dampen the spikes in TKN and P recycle loads to the mainstream process. Sidestream treatment for N and P removal will further reduce plant effluent concentrations.

6.1.2 Nitrogen Removal Optimization

As discussed in Chapter 4, N removal at the PR WWTP can be improved through better carbon management, aeration control, optimized MLR and RAS flow control, and investigation of the sources of soluble effluent organic N. These optimization opportunities are briefly discussed below.

6.1.2.1 Carbon management

Based on evaluation of the historical plant performance data presented in Chapter 4, **the following recommendations may help to reduce further nitrate in the secondary treatment process.**

1. Repeat the detailed influent flow characterization conducted in May 2017 (see Chapter 3) in upcoming summer months (July/August 2018). Process modeling indicated that the influent composition might be significantly different in summer months compared to the late spring season. Collection of an equivalent summer season data set will be helpful to improve future process modeling calibration needed for any upcoming BNR related design projects.
2. Undertake a detailed carbon mass balance across the primary clarification process. VFAs or soluble COD may be produced in the sludge blankets but not be transported over the weirs to the secondary treatment process. Measure the following parameters in the primary clarifier influent, primary clarifier effluent, and primary sludge: COD, sCOD, ffCOD, TSS, total TKN, and TP. If high sCOD concentrations are observed in the primary sludge flow, consider process modifications to route this carbon to the aeration basins. Possibilities may include offline primary sludge fermentation, intermittent primary clarifier mixing, or recycling of a portion of the primary sludge to the primary clarifier influent.
3. Test whether intermittent mixing in the bioselectors may help to enhance N removal and/or P release. Turn the mixers off and monitor the depth profile of solids in these selector basins. Retardation of solids in anaerobic or anoxic selector zones may increase bioavailable carbon for nutrient removal.

4. Track the SRT in the secondary clarifiers as a separate process control parameter using the following equation.

$$SRT_{SC} = \frac{Area_{SC} * Depth_{Blanket} * TSS_{RAS}}{Q_{RAS} * TSS_{RAS}}$$

5. Monitor N removal across the secondary clarifiers on a routine basis and track the relationship between clarifier SRT and nitrate reduction. Develop acceptable process control guidelines to manage the secondary clarifier inventory to maximize N removal while maintaining acceptable secondary effluent quality.
6. Collaborate with the pre-treatment division to investigate available industrial waste flows rich in organic carbon (and low in N and P) in the facility's vicinity. Consider any available options to maximize the benefit of such waste streams to enhance BNR treatment performance, such as brewery waste.
7. Consider the addition of an external carbon feed facility as a future capital improvements project as needed after optimization and lower cost alternatives discussed above have been exhausted.

6.1.2.2 Aeration Control

Improving the aeration control to enhance N removal is directly linked to improving internal carbon management. Elevated air supply beyond the immediate process need for full nitrification biodegrades bioavailable carbon aerobically without benefitting nutrient removal, and unnecessarily increases power costs. **It is recommended the use the following guidelines for future plant operation.**

1. Avoid aeration in the bioselectors if at all possible to minimize loss of incoming carbon without benefiting nutrient removal.
2. Reduce the DO concentrations throughout the aeration basins slowly over time to control filament formation and as low as possible once full nitrification is maintained to maximize the benefit of SNDN.

The recommendations pertaining to the automation of aeration control and intermittent aeration listed in the context of nitrification optimization above are equally relevant for improving N removal as well.

6.1.2.3 Optimization of Mixed Liquor Recycle Flows

MLR returns nitrate back to the anoxic zone for denitrification. MLR flows that are too high for the denitrification capacity of the selectors are indicated by elevated nitrate concentrations at the end of the anoxic bioselectors (nitrate concentrations in excess of 1 to 2 mg/L on a diurnal basis). The denitrification capacity of the selectors is defined by the available volume and available carbon. MLR flows that are too low may be indicated by nitrate concentrations in the bioselector effluent far below 1 mg/L during significant portions of the day. As the facility further lowers effluent nitrate concentrations to very low effluent levels (about 1 to 2 mg/L nitrate), MLR flow will become less important and less cost-effective in further reducing effluent N.

The following recommendations may be useful as guidance for future MLR operation:

1. Use the online nitrate concentrations in the bioselector effluent as a guidance for MLR pump operation. At nitrate concentrations well below 1 mg/L, reduce MLR pumping. This may mean that no mixed liquor is recycled at certain times of the year or during

parts of the day. Track secondary effluent nitrate concentrations in conjunction with MLR flow changes to verify that nitrate concentrations do not deteriorate.

2. Consider automating MLR pump operation in the future with a supervisory control and data acquisition (SCADA) system by tying it to the effluent nitrate probe output in the bioselector effluent.
3. Consider the technical feasibility and cost-effectiveness of installing VFDs on the MLR pumps.

6.1.2.4 Reduction of Effluent Soluble Organic Nitrogen

As discussed in Chapter 4, effluent soluble organic N shows a strong seasonal dependence and has consistently increased in recent years at the PR WWTP. Whether effluent organic N can be reduced through operational adjustments of the liquid or solids stream processes, and how to actually achieve this in day-to-day plant operation, is still a debate that is largely limited to the academic arena. The topic will continue to grow in relevance for many facilities across the country over the coming years and the City is encouraged to stay abreast of this discussion and consider active participation in related research and collaboration efforts as opportunities arise. Of equal interest are ongoing research efforts that attempt to better characterize which fractions of effluent organic N can become bioavailable in receiving waters and which once are recalcitrant.

It is further recommended to closely monitor whether any operational modifications or process changes undertaken at the PR WWTP increase or decrease the organic N concentrations in the final plant effluent.

6.1.3 Phosphorus Removal Optimization

P removal efficiency at the PR WWTP has fluctuated in the past as discussed in Chapter 4. It is anticipated that biological P removal will become more stable when nitrification and denitrification has been optimized following recommendations listed above. In addition, the City can undertake additional measures as described below to stabilize P removal in the secondary treatment process and lower concentrations consistently in the final effluent.

6.1.3.1 Boosting VFAs through In-situ Fermentation

In order to achieve stable enhanced biological P removal, the PAOs require sufficient VFAs. Approximately 8 to 12 milligrams (mg) of VFAs are needed per mg TP to be removed (Table 6.1). Special sampling conducted in May 2017 indicates that the primary effluent typically contains sufficient carbon to allow for a high P removal efficiency.

Table 6.1 Guideline for Secondary Influent Water Quality to Achieve Biological P Removal

Biological P Removal Efficiency	BOD/TP	COD/TP	VFA/TP
Low	15-20	25-35	-
Medium	20-25	35-45	8-12
High	>25	>45	-
PR WWTP(1)	NA	46-96	16-41 (ffCOD/TP)

Notes:
(1) Based on the results of the 2-week sampling campaign in May 2017.

Based on these results, **the following recommendations can help the facility to make the most of the available carbon in the wastewater influent:**

1. Include sCOD or ffCOD and TP sampling in the primary effluent as a monthly routine analysis to identify potential periods throughout the year when bioavailable carbon may be limited for P removal in the secondary treatment.
2. Assess how to maximize the effectiveness of primary sludge fermentation to boost bioavailable carbon in the aeration basin influent (see related recommendations above).
3. Evaluate the feasibility of mixed liquor fermentation in the unaerated bioselectors (see related recommendations above).
4. Monitor on a weekly basis OP concentrations in the effluent of the unaerated bioselectors to assess the effectiveness of the biological P removal process. This concentration should be at least 15 to 20 mg/L (ideally higher) to achieve effective biological P removal. If the concentration is lower and OP is present in the plant effluent at elevated concentrations, this indicates a carbon limitation. Investigate possible causes, which include low sCOD concentrations, high P concentrations (from recycle flows), or high nitrate recycle loads (or a combination thereof).

6.1.3.2 Stable Anaerobic Preconditioning of P Removing Bacteria

PAOs require stable anaerobic conditions with ORP levels below at least -100 mV or below in order to function metabolically, meaning to effectively release OP under anaerobic conditions and uptake OP under subsequent aerobic conditions. At this time, the PR WWTP does not have a dedicated anaerobic treatment zone as MLR can only be returned to the head of the unaerated bioselectors.

The following recommendations can help stabilize P removal in the future and lower OP concentrations in the final effluent further:

1. Monitor nitrate occasionally in the influent to the bioselectors and at the end of the bioselectors. If nitrate concentrations are low (< 1 mg/L) in the influent and effluent, turn MLR pumps off unless this causes final effluent nitrate concentrations to rise. Profile testing (described in Chapter 4) indicated that MLR may not be needed at all times throughout the year. This operation will save energy and is likely to improve OP removal.
2. Provide the flexibility to route MLR to the second bioselectors. This will create a dedicated anaerobic and anoxic zone and provides plant staff with more flexibility in the future to balance biological N and P removal (see further discussion in Chapter 7). Process modeling indicates that relocation of the MLR flow may decrease OP effluent concentration by about 0.3 mg/L and that the tradeoffs on nitrate removal are marginal (up to 1 mg/L). Actual process operation may achieve better results in combination with the optimization opportunities discussed in this chapter that were not integrated into the process model.
3. Occasionally monitor the OP profile through the aeration basins and the secondary clarifiers. An increase in OP concentrations in unaerated zones in the aeration basins or in the secondary clarifiers may indicate secondary P release, which can occur when PAOs are exposed to reduced environments downstream of the unaerated selector. This needs to be avoided.
4. Periodically conduct microbial evaluations of the biomass in the aeration basins through phase contrast microscopy. Use Neisser staining to differentiate between GAOs and

PAOs. Activated sludge can be sent to a lab conducting molecular biology fingerprinting to quantify GAOs and PAOs; however, this is more expensive. GAOs compete for the same carbon but do not remove P and are therefore not desired. GAOs are particularly prone to proliferate in BNR processes that operate under the following conditions:

   a. COD: P ratios above 50.
      i. The PR WWTP has COD:P ratios at times far in excess of this threshold in the aeration basin influent.
   b. Warm climates and during summer months.
      i. Traditionally, the PR WWTP has had difficulties in summer months to maintain effective P removal.
   c. Low pH conditions (less than about 7.25).
      i. PAOs are able to take up VFAs faster than GAOs as elevated pH ranges between about 7.25 and 8.
   d. Extended SRTs.
      i. There is still scientific debate on the role of SRT on the competition between GAOs and PAOs, but some field data indicate that SRTs in excess of 10 days can diminish the competitive growth advantage of PAOs.

5. Consider the addition of chemical P removal as a backup process to the biological treatment to trim OP concentrations when necessary (see further discussion in Chapter 7).

6.1.3.3 Side-Stream Phosphorus Removal

Sidestream treatment for P removal is an even higher priority than for NH_4-N removal (see discussion above). P recycle loads as a fraction of the plant influent amount to about 20 percent to over 50 percent as observed during the May 2017 sampling campaign. Thus, all recommendations stated above in the context of improving nitrification through better sidestream management are equally applicable to improving P removal.

While process improvements through sidestream treatment could not directly be simulated at full-scale, the facility undertook a full-scale optimization test in 2017 by withholding filtrate recycle for a week from the mainstream BNR process. Results of this test are described below. **In addition, the following recommendations may help manage P recycle loads better in the future:**

1. Assess whether the current practice of lime addition improves chemical P removal in the sidestream through focused process sampling. Assess the cost-effectiveness of lime addition for removing P from the sidestream chemically.
2. Consider the cost-effectiveness and technical feasibility of metal salt addition to the belt filter feed for P removal in the sidestream recycle and impact on dewaterability. (The PR WWTP has a ferric feed facility on site located on the south side of the site for the solids handling process.)
3. Evaluate the cost-effectiveness of an OP sequestration process in the future to bind and remove OP as struvite or brushite from the liquid stream process and its recovery as a fertilizer if desired. This will also reduce unintentional struvite formation in solids process piping, reactors, and equipment in the future and associate maintenance costs for prevention and removal.

6.1.3.4 Consistent Particulate Phosphorus Removal

Typically, the PR WWTP does not experience breakthrough of particulate P in the final plant effluent due to effective tertiary filtration. **In order to maintain consistent and low particulate P concentration in the final effluent, the following is recommended:**

1. Drain sludge holding tanks and other reactors in a controlled manner when units need to be taken out of service for maintenance or cleaning.
2. Inspect the final cloth filters frequently for damaged units and perform timely repairs.
3. Evaluate the cost-benefit of moving from cloth filters to deep bed media filtration in the future to further reduce effluent P concentrations. The current cloth filters typically achieve final effluent TSS concentrations of about 2 to 3 mg/L. About 5 percent of the TSS in biological P removing processes is P by weight. This means that about 0.15 mg/L particulate P are consistently passing through tertiary filtration. This accounts already for 50 percent of the final effluent target of 0.3 mg/L TP. Deep bed filters can achieve a higher degree of solids removal and allow for chemical addition ahead of the filters to reduce effluent P further. (Chemical addition upstream of cloth filters is not recommended without prior coordination with the filter manufacturer and full-scale testing. Several facilities have experienced operational issues and concluded that this is not a feasible process operation.)

6.2 Summary of Recommendations for Nutrient Removal Optimization

As part of this study, full-scale process optimization testing was initiated at the PR WWTP in the fall of 2017 and plant staff was supported by Carollo Engineers, Inc. (Carollo), in the planning, execution, and evaluation of the results of selected optimization test that were identified to be of highest priority. Plant staff selected the following three optimization strategies for implementation testing in 2017/2018 that focused on improvement of nitrification and denitrification.

1. Temporary Storage of Dewatering Recycle Flows.
2. Optimization of MLR Recycle Flows.
3. Alternative Aeration Patters in the Aeration Basins.

The results of these tests are discussed in the following sections. The test plans that were developed for Tests 1 and 2 ("Temporary Storage of Dewatering Recycle Flows" and "Alternative Aeration Patters in the Aeration Basins" respectively) are included for reference in Appendix B.

As an immediate first step, it was recommended early on in this project to acquire and install key online instrumentation probes and analyzers to support process optimization testing during this study and beyond. The online instrumentation that was installed at the PR WWTP to help improve nutrient removal is summarized in Section 6.4 below.

6.3 Acquisition and Placement of Online Instrumentation

Table 6.2 summarizes the online instrumentation that the City procured and installed in 2017 to support nutrient optimization efforts. The project memorandum (PM) that was finalized in May 2017 by Carollo to summarize the recommended instrumentation to be purchased is included for reference in Appendix C. The integration of these instruments into a plant-wide SCADA system is planned by the City to be completed in an upcoming separate capital improvements project.

Table 6.2 Online Instrumentation Installed at PR WWTP During Study

Instrument	Locations	Comment
DO Analyzers (4)	North and South Aeration Basins (2 each)	Relocatable between Passes A and B and C and D
Nitrate Probes (2)	End of Unaerated Bioselector (1) D Pass in South Aeration Basin (1)	Relocatable between all four bioselectors
Ammonia Analyzer (1)	End of the C Pass in the South Aeration Basin	
Shimatzu Multi-Parameter Analyzer (1)	Final Effluent - Post UV	Hourly analysis of total organic carbon (TOC), TP, and TN

Notes:
(1) The number in parentheses refers to the number of instrument units.

6.4 Results of Full-Scale Optimization Testing

6.4.1 Temporary Offline Storage of Dewatering Recycle Flows

6.4.1.1 Objectives and Testing Plan

The objective of this full-scale test was to assess the potential improvements in effluent quality that could be achieved through better management of the nutrient recycle loads from filtrate recycling through sidestream treatment. Sidestream treatment of the filtrate for P and/or N removal may be a cost-effective strategy for the PR WWTP to reduce effluent nutrient concentrations further.

The specific testing goals were as follows:

- Quantify the improvement in secondary and final plant effluent N and P concentration without filtrate recycling to the mainstream.
  - Simulate mainstream treatment operation and performance full-scale under simulated sidestream treatment of filtrate for N and P removal.
- Identify any other potential plant-wide consequences (negative or positive) of operating the mainstream treatment without filtrate recycle loads.

The detailed testing and sampling for this optimization test is included in Appendix B.

6.4.1.1 Results

The impact of removing the filtrate return flow on plant performance was evaluated by diverting this flow to an empty primary clarifier. It was intended to last for 7 days, however, filtrate flow rates were greater than expected, filling up the clarifier more rapidly such that the test only lasted for 4 days. The testing was conducted between August 28 and September 14, 2017. Baseline data was collected between August 28 and September 9, 2017. Filtrate began to be stored in the offline primary clarifier on September 10, 2017. The plant influent flows stayed very stable at 5.0 mgd throughout both periods.

The filtrate flows fluctuated during the test period when stored in the primary clarifier. The test had to be stopped after 4 days, as the primary clarifier was reported to be full. Based on the filtrate flow records during this time, it is estimated that a total of 216,000 gallons of filtrate were produced over the 4 days and stored in the primary clarifier. The recorded cumulative filtrate flow accounts for only about 40 percent of the primary clarifier capacity. The remainder of the flow was washwater from the belt filter presses. The test period altogether was not long enough to draw reliable conclusions about the impact of filtrate loads on the BNR performance in the mainstream treatment.

Figures 6.1 and 6.2 show the plant influent P and N concentrations during the baseline and testing phases. Clearly, the influent OP load was significantly lower when filtrate was not recycled to the headworks (Figure 6.1), which confirms other data showing that the filtrate return flow constitutes a significant fraction of the total phosphorous load on the plant. The particulate P load concentration in the influent stayed relatively constant.

Without filtrate recycle, the influent load remained far more stable. During each Saturday of the baseline period (August 30 and September 7, 2017), the influent OP concentration increased by about 4 to 8 mg/L. This increase was significantly less during the testing period (less than 1 mg/L).

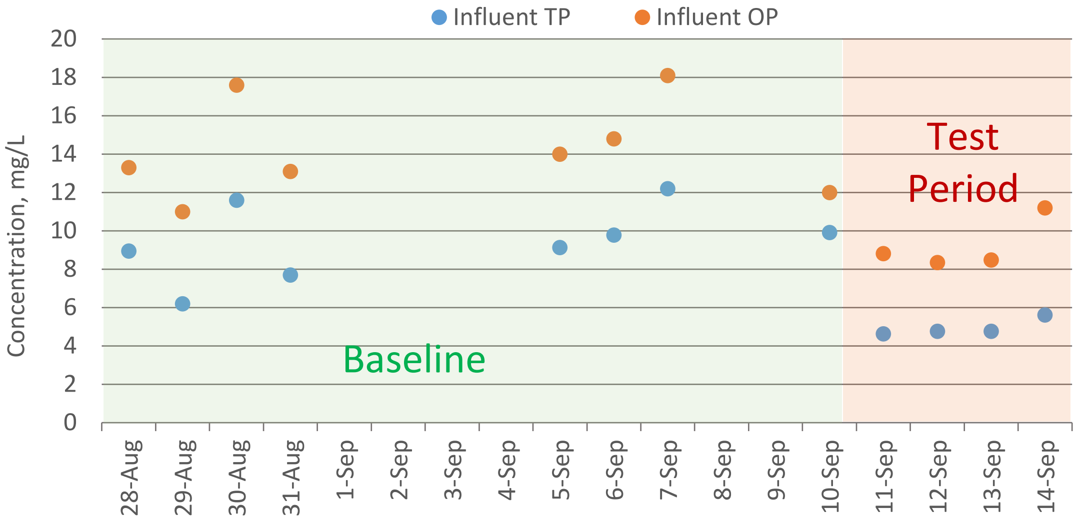


Figure 6.1 Plant Influent TP and OP Concentrations During Filtrate Storage Testing

Although less pronounced, a similar load pattern was observed for the influent NH_4-N load with higher concentrations in the plant influent on Saturdays when filtrate was recycled (Figure 6.2). This indicates that the filtrate recycle streams are responsible for the weekly NH_4-N effluent pattern (see discussion in Chapter 4, Figure 4.6) and the cause for the high effluent concentrations on weekends.

Altogether, the NH_4-N influent concentrations were less noticeably affected by filtrate recycle compared to P concentrations.

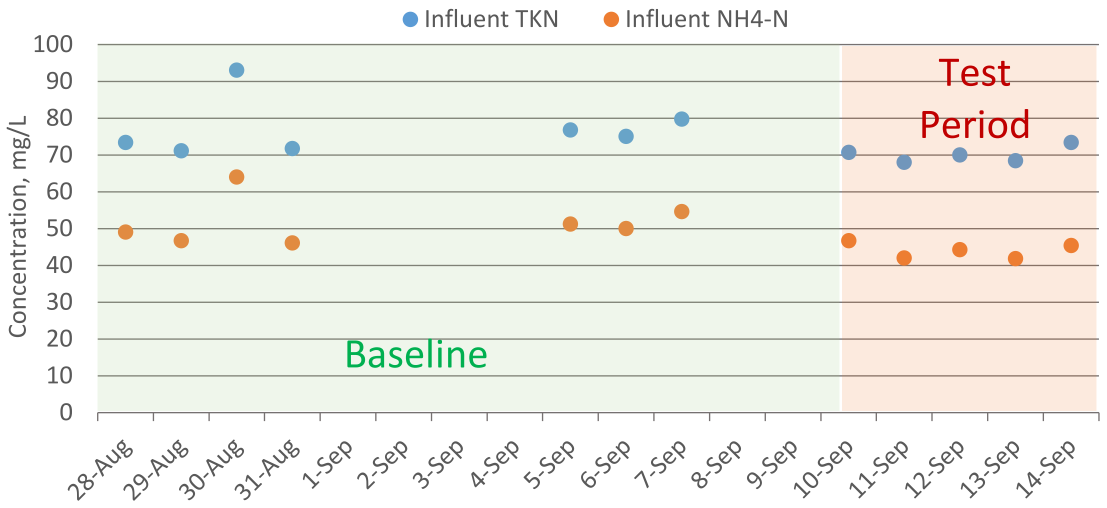


Figure 6.2 Plant Influent TKN and NH_4-N Concentrations During Filtrate Storage Testing

The testing was not successful in assessing the impact of filtrate recycle on effluent nutrient concentrations due to the short duration of the testing period (4 days). Also, the stable P removal performance observed during most of the baseline period was lost towards the end before the filtrate was stored. Whatever affected the process performance likely impacted the P removal performance during the testing period as well. On average, the OP effluent concentration during the baseline testing was 0.9 mg/L compared to 1.0 mg/L during the test period (Figure 6.3).

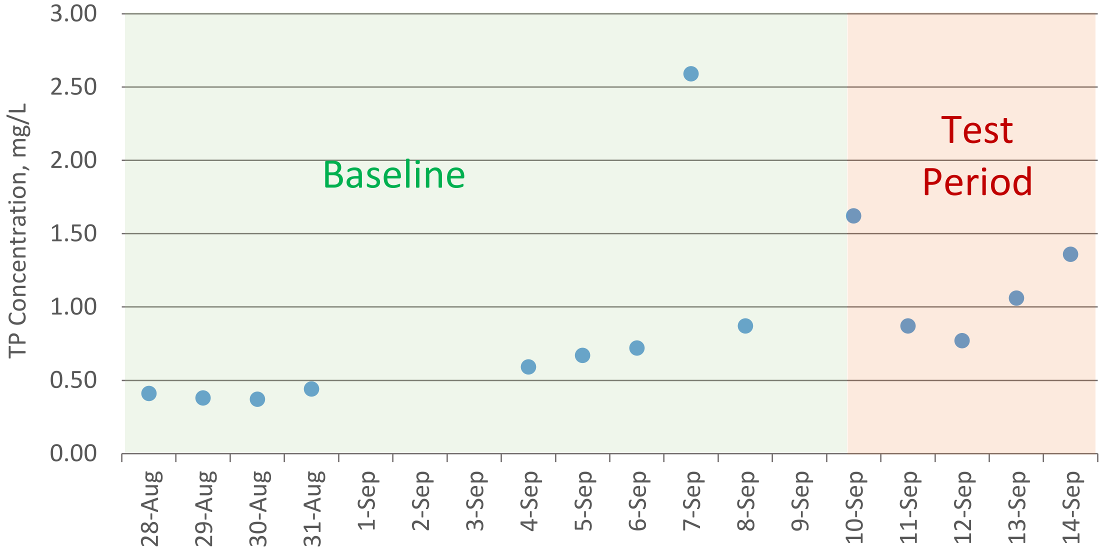


Figure 6.3 Plant Effluent TP concentrations During Filtrate Storage Testing

Interrupting filtrate recycle to the mainstream had no noticeable effect on the effluent NH_4-N and TKN concentration (Figure 6.4). The anticipated impact was low as filtrate accounts for not more than about 15 percent of the influent TKN load. Given the variability in effluent concentrations, a longer testing period would be required to demonstrate statistically relevant results.

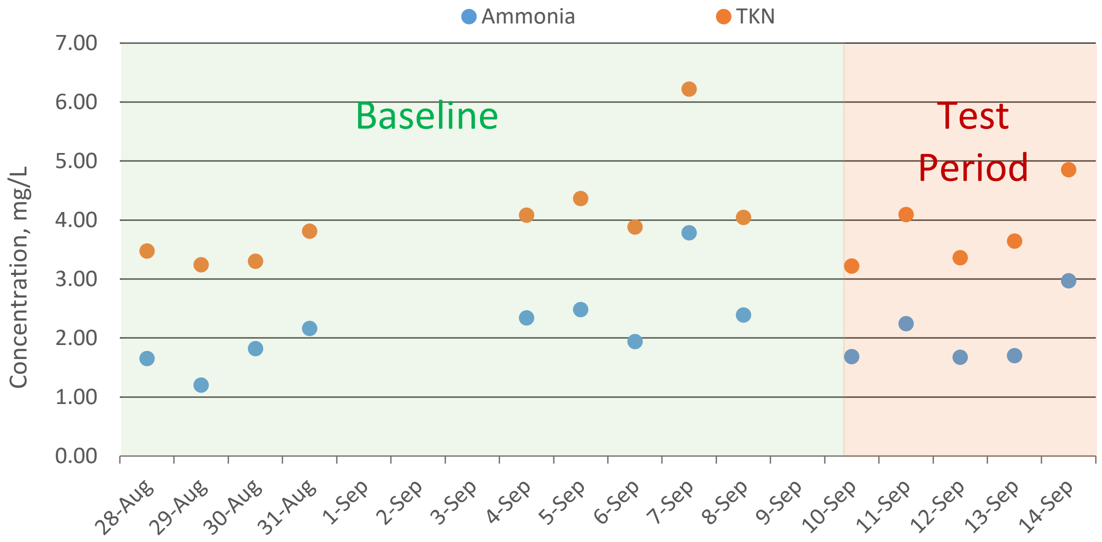


Figure 6.4 Plant Effluent TKN and NH4-N Concentrations During Filtrate Storage Testing

6.4.1.2 Conclusions

The following conclusions were gained from the filtrate offline storage testing:

1. The filtrate recycle stream adds significant P (and to a lesser extent N) loads to the plant influent. If sidestream treatment is considered, P removal should be prioritized.
2. Filtrate recycling is the main cause for influent load variability to the secondary treatment system. Peak influent loads on weekends coincide with effluent NH_4-N peaks. Filtrate flow equalization is recommended near-team to buffer out weekend spikes.
3. The testing period was too short to determine a statistically significant difference in effluent quality between baseline and testing performance.

6.4.2 MLR Flow Adjustments

On August 1, 2017, plant staff reduced the MLR flows to the unaerated bioselectors. Prior to this date, plant staff operated with two of the pumps (5 mgd each) during the day and reduced the MLR flows during the night to 5 mgd with one pump in service. Since August 2017, only one MLR pump has been in operation throughout the day. Figure 6.5 shows that effluent nitrate was not negatively impacted by this flow reduction. Effluent TP have remained quite consistently below 0.5 mg/L since August 2017. It is recommended to continue to use the nitrate probe online data from the bioselector effluent to adjust MLR flows in the future (see Section 6.1.2.3).

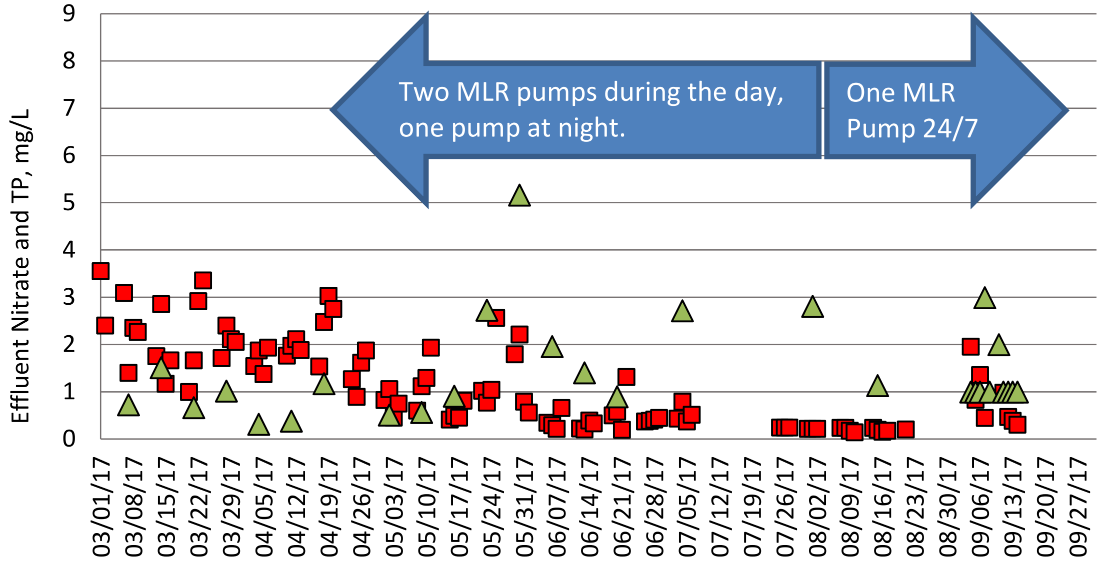


Figure 6.5 Effluent Nitrate and TP Concentrations During MLR Flow Adjustments

6.4.3 Modified Aeration Patterns and DO Setpoints

6.4.3.1 Objectives and Testing Plan

The objective of the full-scale testing of modified aeration patterns and DO setpoints was to assess the potential improvements in effluent quality that may be achieved through improved nitrification and denitrification.

The specific goals of the testing were as follows:

1. Assess the optimal oxygen profile throughout the aeration basins for completely removing NH_4-N while keeping the DO profile as low as possible to maximize the removal of N in the secondary treatment.
2. Identify the most beneficial DO pattern along the length of the aeration basins to maximize the amount of SNDN.
3. Assess any other potential plant-wide consequences (negative or positive) of operating the mainstream treatment without filtrate recycle loads.

The detailed testing and sampling for this optimization test is included in Appendix B. Figure 6.6 shows a schematic of the alternative aeration pattern that was recommended be tested between December 2017 and January 2018 in an effort to improve nitrification and denitrification. In contrast to the standard aeration pattern that the facility had operated under over past years (see Figure 1.3 in Chapter 1), this mode introduces an alternating pattern of aeration and non-aeration in Passes A through D. The intention was to a) maximize SNDN performance through alternating aeration maintaining low DO concentration throughout larger segments of the aeration basin; and b) reduce the large volume with no detectable DO concentration in Pass D that may lead to ammonification. Actual aeration patterns that were tested varied from the recommendation due to other process considerations. These patterns are provided in Appendix D.

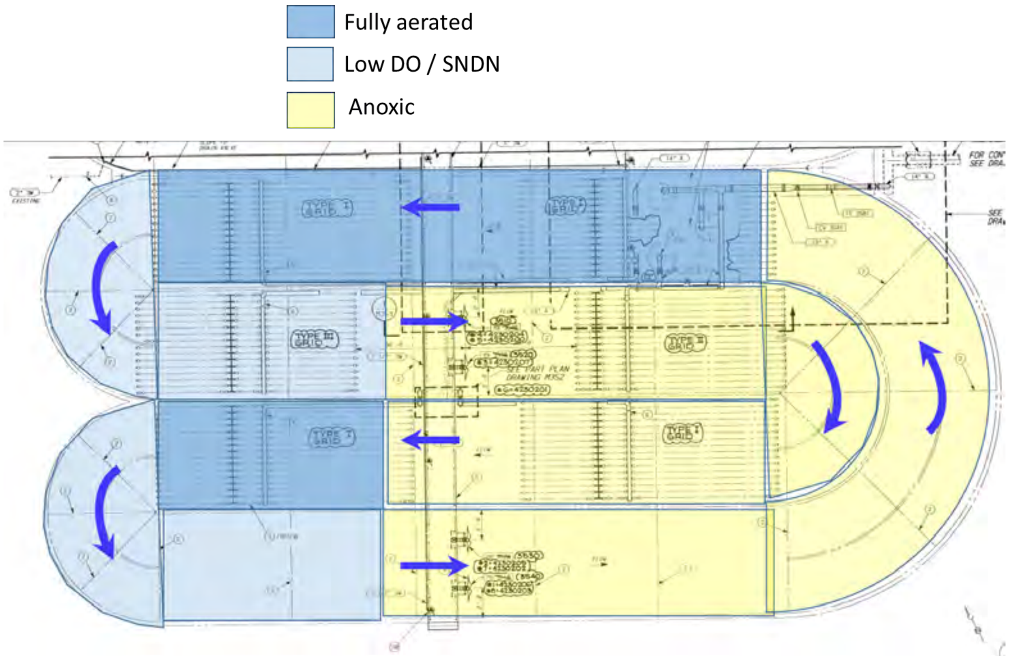


Figure 6.6 Alternative Aeration Pattern in Aeration Basins

6.4.3.2 Results

Figure 6.7 shows the typical diurnal DO profiles in the South Aeration Basin A and D Passes (where the two DO probes were located) along with plant effluent nitrate and NH_4-N concentrations. Traditionally, the plant operated at high DO concentrations in the A Pass between 1 and 6 mg/L and at somewhat reduced DO concentrations in the B Pass (about 1.5 mg/L), while the C Pass was not aerated.

At the beginning of November 2017, plant staff reduced the DO concentrations in the A Pass to 1 to 2 mg/L. As a consequence, effluent nitrate concentrations dropped below 4 mg/L, while effluent NH_4-N concentrations remained relatively stable at or below 1 mg/L. DO was fully consumed in the B and C Passes and not detectable in the D Pass (Figure 6.7).

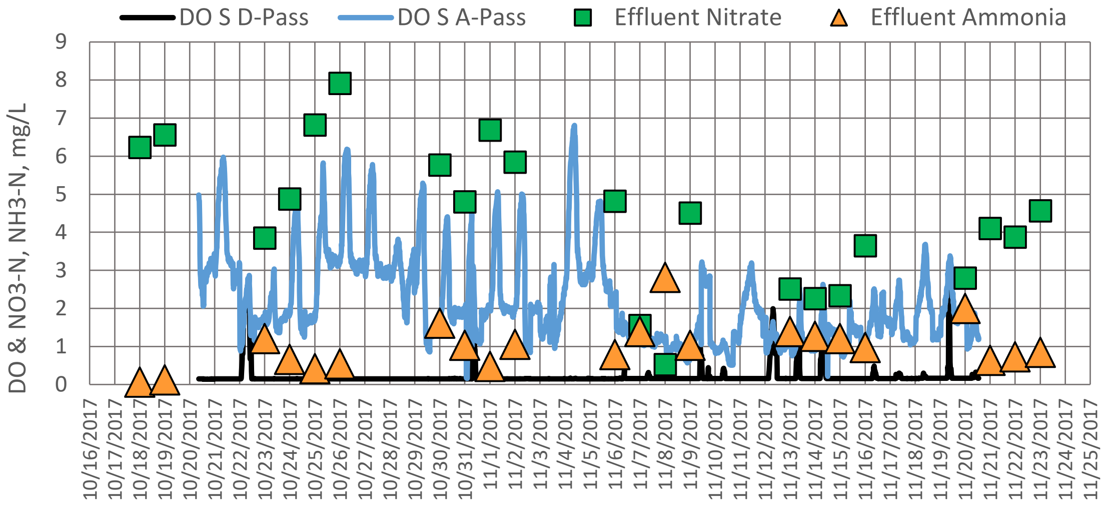


Figure 6.7 Aeration Reduction in November 2017 and Effect on Effluent NH_4-N and Nitrate

The alternative aeration pattern was implemented around December 20, 2017. The target DO concentrations under this operation were as follows:

- A Pass: DO 1.0 to 1.5 mg/L.
- B Pass: First grid OFF, second grid DO 0.5 to 1.0 mg/L.
- C Pass: Both grids ON - DO Setpoint 0.3 to 0.5 mg/L.

Figure 6.8 shows the DO profile throughout the month of December in the A and C Passes. Effluent NH_4-N started to rise at the beginning of December when the diurnal DO variability in the A and C Passes were rapidly reduced and DO concentrations were held steady at 1 mg/L and 0.2 mg/L. At the same time, denitrification improved drastically and effluent nitrate dropped from about 5 mg/L to less than 1 mg/L.

Over the following week (12/7/2017 to 12/14/2017), the effluent NH_4-N and nitrate remained stable around 4 to 6 mg/L and 1.3 mg/L, respectively. The elevated NH_4-N concentration was a warning that the DO adjustments and reduction was too rapid for the nitrifying population. Over the next 2 weeks, the DO levels in the A Pass dropped dangerously low twice, leaving the aeration basin with essentially no air for nitrification (third and fourth weeks in December, see Figure 6.8). When the air to the C Pass was mistakenly completely turned off after Christmas, effluent NH_4-N spiked up to 18 mg/L. The DO in the B Pass was typically below 0.5 mg/L and therefore lower than the target setpoint with valves only 1/8 to 1/4 open. Throughout most of the December period, no substantial DO concentrations were recorded in the C Pass of the South Basin. The airflow to the C Pass may have been intentionally limited by operations staff due to concerns that aeration of the C Pass results in basin foam being pushed over the effluent weir and into the secondary clarifiers and disc filters.

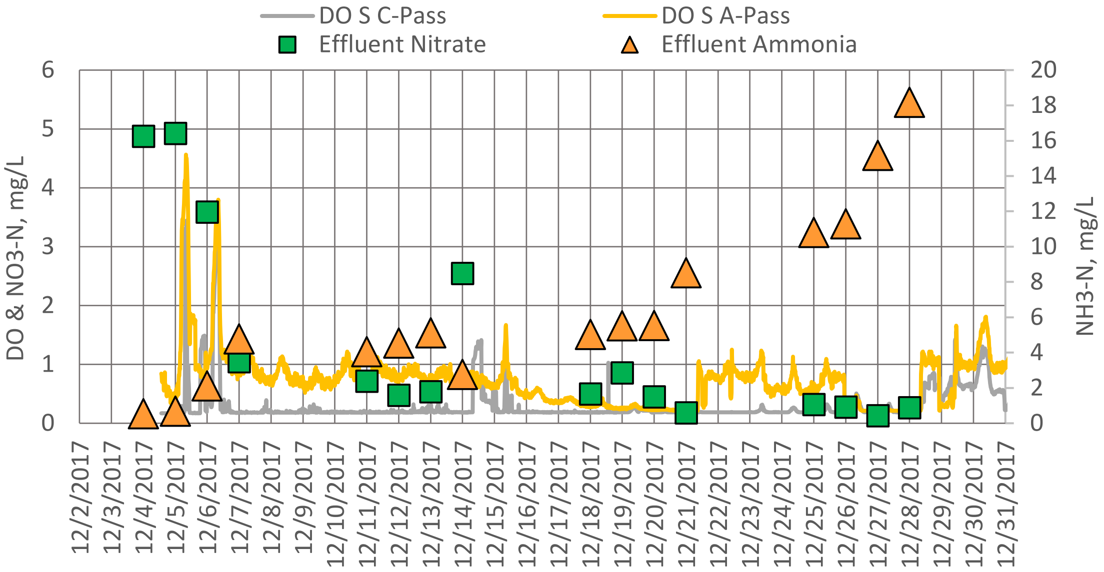


Figure 6.8 DO, Effluent NH_4-N, and Effluent Nitrate in South Aeration Basin During December 2018

Between December 28 and January 11, plant staff was successful in maintaining aeration in the A and C Passes close to the target DO setpoints of 1 to 1.5 (A Pass) and 0.3 to 0.7 mg/L (C Pass) (Figure 6.9). Nitrification partially recovered and dropped below 4 mg/L on January 9, 2018. Figure 6.9 shows that it was still challenging to equalize the DO concentrations between the

North and South train. Generally, DO concentrations in the North Train stayed far below the target concentrations. Since NH_4-N concentrations are not monitored in both trains, it is not possible to determine whether the air supply provided to the South Train during the first part of January was sufficient to lower TN concentrations in the final effluent.

Subsequently, the DO concentrations were further increased to bring NH_4-N in the plant effluent back below 1 mg/L, but this was only effective in the South Train (Figure 6.9). The total SRT during this period was approximately 11 days and DO concentrations measured in the D Pass varied between 0.04 and 0.1 mg/L.

Despite significant efforts by plant staff, the DO concentrations started to fluctuate significantly again throughout the day since the middle of January in the South A Pass.

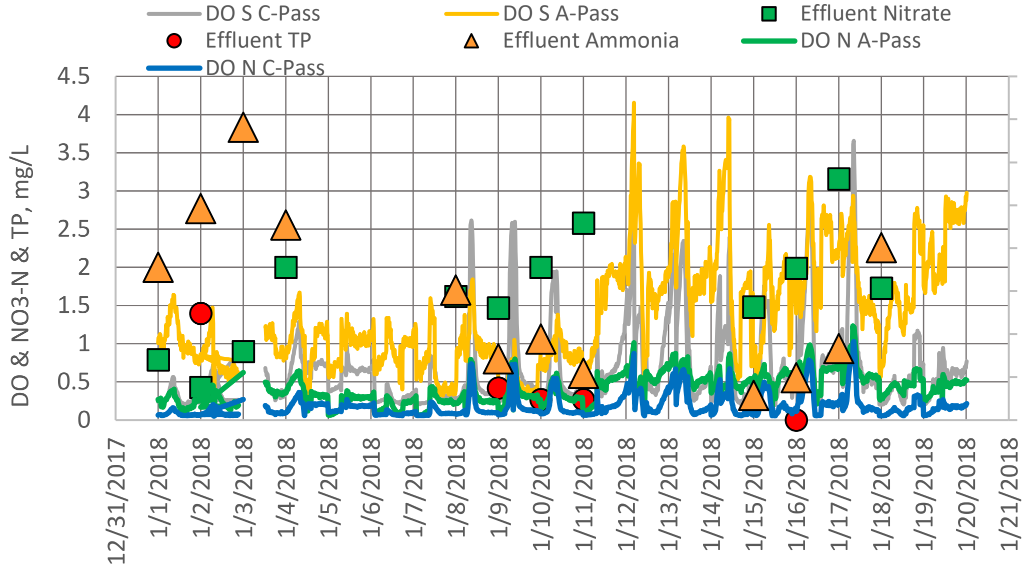


Figure 6.9 DO and Effluent NH_4-N, Nitrate, and TP in South Aeration Basin During January 2018

In the middle of January, nitrification had completely recovered and effluent TN concentrations dropped again into the 4.5 to 7 mg/L range. At this time, plant staff made air adjustments every 2 hours.

The subsequently observed NH_4-N increase was likely caused by a higher dewatering throughput when both filter presses were taken into operation, resulting in higher filtrate recycle flows. Plant staff also struggled with keeping enough air in the C Passes under increased loads in the early evenings. Whenever the DO in the C Passes dropped below 0.5 mg/L, plant staff observed an increase in effluent NH_4-N.

In the third week of January, the wastewater temperature dropped while plant staff maintained an SRT of about 11 to 12 days. The SRT was subsequently increased to 15 days at the end of January.

In February 2018, plant staff installed additional DO probes in both aeration basin trains and converted back to the aeration of the A and B Passes. The C Pass remained unaerated. Figures 6.10 and 6.11 show the DO concentrations in all three passes over the first 2 weeks of

February. The DO setpoints are close to the original concentrations that the utility targeted prior to November 2017 (see Figure 6.7).

- A Pass: DO 2.0 to 3.5 mg/L in the North, 1.0 to 2.0 mg/L in the South.
- B Pass: DO 1.0 to 2.0 mg/L.
- Pass C: Not aerated.

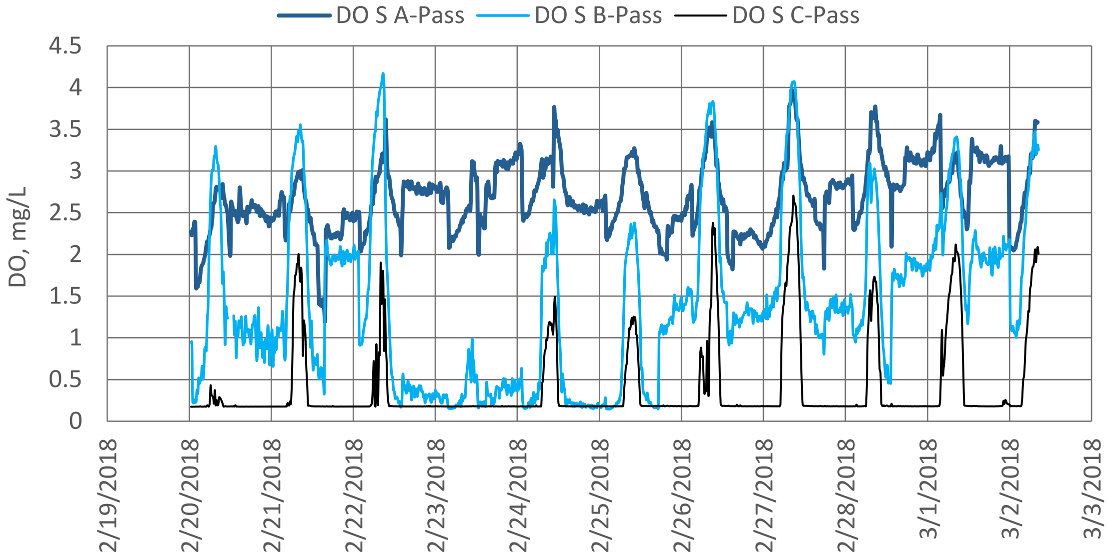


Figure 6.10 DO Profile in South Aeration Basins During February 2018

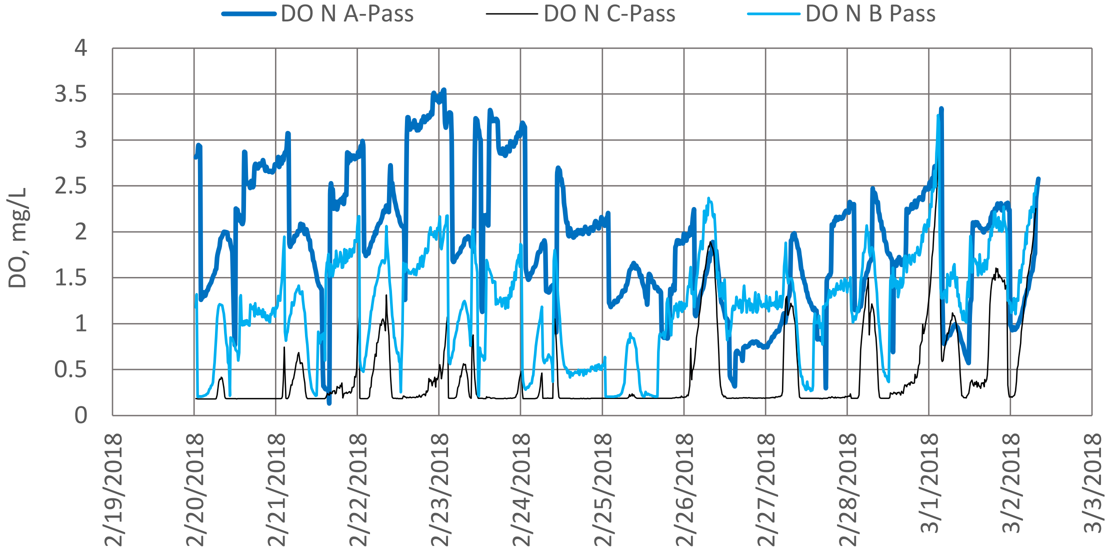


Figure 6.11 DO Profile in North Aeration Basins During February 2018

This operation resulted also in very similar effluent NH_4-N, nitrate and TN concentrations in the final effluent as achieved prior to November 2017 (Figure 6.12). Since October 2017, TP concentrations measured in the final effluent remained typically below 0.5 mg/L and were not significantly affected by the aeration changes undertaken throughout December to March.

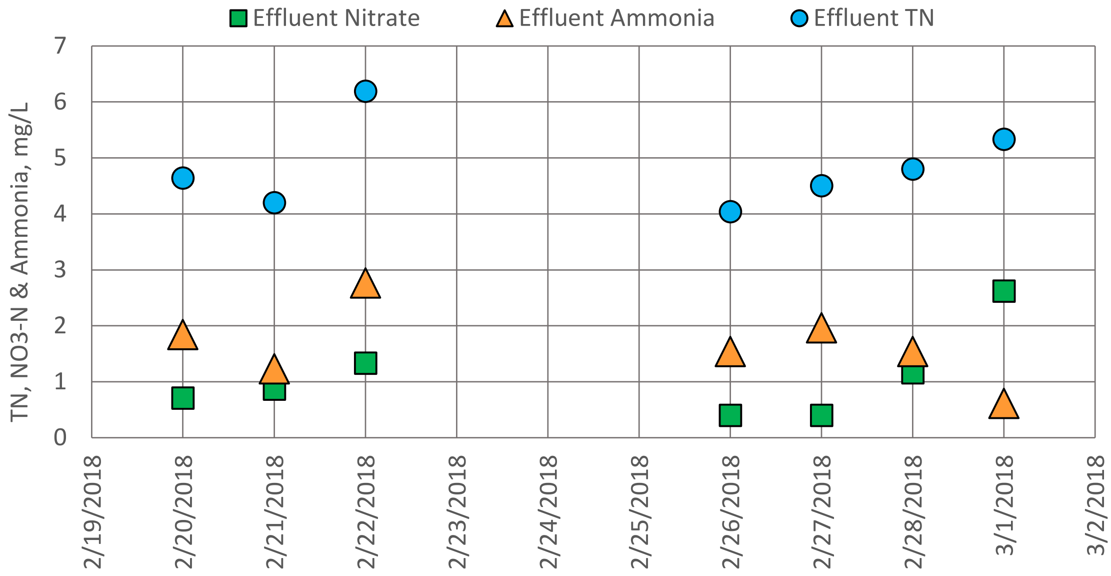


Figure 6.12 Effluent Nitrogen During February 2018

6.4.3.3 Conclusions

The following conclusions were gained from testing alternative aeration patterns and DO setpoints:

1. Implementing an alternate aerobic/anoxic redox condition in the aeration basins is challenging at this time and proved ultimately unsuccessful given the current aeration system limitations. This would require aeration of the C Pass which is challenging for two reasons.
    a. DO control is very difficult in the C Pass and plant staff struggled to maintain minimum DO target set points.
    b. Aeration of this zone causes foam that is trapped in the aeration basins to leave over the basin effluent weir causing concerns of blinding the cloth filter screens.
2. Maintaining DO target concentrations in any of the zones throughout the day required constant operator attention and even then was nearly impossible. DO automation is required to be able to gain sufficient DO control in order to further lower TN effluent concentrations.
3. The DO profiles in the North and South trains are significantly different. It is important to understand the cause of this discrepancy (unequal flow or load split, uneven air flow distribution). Automated DO control will help to balance out operation between both trains. Plant staff recently installed a second NH_4-N probe. It is also recommended that plant staff consider permanently relocating nitrate probes from the selector zones to the North and South Trains to see if that provides more valuable information for process control.
4. Once DO control is automated, plant staff will have better aeration control to repeat this test of different aeration patterns and DO setpoints. It is recommended to combine such testing with profile testing throughout the basins in order to better understand where nitrification and denitrification is limited and make adjustments accordingly.
5. Future aeration system modifications should include the ability for intermittent aeration of the aerated zones to improve SNDN operation (on/off cycling).

6.5 Summary of Recommended Capital Improvements

Several of the recommendations listed in this chapter require capital improvements. In Chapter 7, Carollo grouped these capital improvements into the four effluent tiers (introduced in Chapter 2) that will allow the facility to meet progressively tighter effluent limits for P and N. Budgetary cost estimates for each of these capacity improvements and by effluent quality tiers are summarized in Chapter 7.

Chapter 7

CAPITAL IMPROVEMENTS FOR ACHIEVING FUTURE EFFLUENT NUTRIENT TIERS

The purpose of this chapter is to summarize the capital improvements that are required to achieve the different effluent nutrient tiers that were introduced in Chapter 2 and present the preliminary cost estimates for these improvements. All costs presented herein are based on a capacity of 13 mgd ADMMF. As discussed during the final project workshop, the facility should consider de-rating the capacity of the facility from 13 mgd if buildout flow projections do not support this flow.

7.1 Summary of Recommended Alternatives

The recommended projects for the PR WWTP are grouped into four tiers of effluent limits and are summarized as follows and presented in Table 7.1:

- Tier 1 – Optimization of the Existing Process to achieve TP of less than 1 mg/L and TN of 3 to 5 mg/L:
    - Upgrades to aeration system.
    - MLR modifications.
    - Filtrate equalization.
    - Sidestream treatment.
- Tier 2 – Construction of additional processes to achieve TP of less than 0.5 mg/L and TN of 2 to 4 mg/L:
    - MBR Treatment with chemical addition.
- Tier 3 – Construction of additional processes to achieve TP of less than 0.2 mg/L and TN of 2 to 3 mg/L:
    - Tertiary treatment with chemical addition.
- Tier 4 – Construction of additional processes to achieve TP of less than 0.1 mg/L and TN of less than 1 mg/L:
    - Membrane filtration/reverse osmosis treatment.

Table 7.1 Technology-Based Effluent Tiers for N and P for Surface Water Discharge

Parameter	Status Quo	Tier 1	Tier 2	Tier 3	Tier 4
Representative Treatment Technology	Existing BNR Process	Optimization of Existing Process	MBR Treatment with Chemical Addition	Tertiary Treatment and Chemical Addition	Reverse Osmosis Treatment
TP, mg/L	1-5	<1	<0.5	<0.2	<0.1
TN, mg/L	5-7	3-5	2-4	2-3	<1

7.2 Cost Estimate Methodology

The Conceptual Design Cost Estimates provided herein represent a Class 4 level of detail cost estimate prepared based on the conceptual design of the projects as outlined in herein. The Effective Price Level Date for the estimate is February 2018.

Carollo uses standardized guidelines and templates for completing construction cost estimates based on recommended practices from the Association for the Advancement of Cost Engineering (AACE). This software includes unit costs derived from commercially available cost guide databases that report current pricing for a wide variety of construction elements associated with water, wastewater, and industrial facility construction projects.

7.3 Cost Estimate Components

7.3.1 Construction Costs

The construction costs include all direct labor costs, purchased materials, and process equipment needed for the recommended projects. At this stage of costing, percentages were applied to cover mechanical and electrical, instrumentation, and control (EI&C) costs. A percentage of the direct cost was used for general conditions, which includes field administration, mobilization, demobilization, insurance, and bonds.

Based on the AACE guidelines for this level of estimate, an estimating contingency of 30 percent was applied to the direct cost. An estimate of 15 percent of the total direct cost was used for the contractor’s overhead, profit, and risk.

7.3.2 Administration Costs

An estimate of 15 percent of the total construction cost was used for engineering, legal, and administration fees. An additional 5 percent was included as an Owner’s reserve for Change Orders.

The summation of the construction costs and administration costs as described herein represents the total estimated project cost.

7.4 Recommended Projects and Cost Estimates

The cost estimates for the recommended projects in each tier are presented in the following sections. Additional details for each cost estimate can be found in Appendix E.

7.4.1 Tier 1 Recommended Projects

Tier 1 includes multiple smaller projects that may be performed altogether or individually, as determined by plant staff based on desired plant performance. These projects were developed based on the optimization efforts described in Chapter 6.

7.4.1.1 Upgrades to Aeration System

The first project in Tier 1 includes upgrades to the existing aeration system, including diffuser replacement, blower replacement, automation of DO control, and pipe routing for backup chemical P removal.

There are a total of 7,658 diffusers in the existing aeration basins, 1,273 of which have recently been replaced. As such, this estimate includes replacement of the remaining 6,385 diffusers, at an assumed cost of $4 per diffuser. This recommendation is based on findings documented in the Report of Full Scale Offgas Analysis of Membrane Grid Aeration System by the Redmon Engineering Company (Appendix F).

Based on the long-term aeration requirements as identified in Chapter 5, this estimate assumes the installation of three new single-stage blowers, each with a capacity of 5,500 scfm (2 + 1 standby). This provides firm aeration capacity of 11,000 scfm at 20-year projected flows of 8.5 mgd.

As discussed in Chapter 6, automation of DO control is needed to fully optimize nitrification and denitrification in the aeration basins. This project assumes the replacement of a total of 12 isolation valves with new motorized operated valves on the aeration droplegs, in addition to the EI&C associated with automating the aeration system. In addition, Carollo recommends integrating the online instrumentation into the future SCADA system to provide the basis for implementing automated DO control.

Finally, Carollo recommends routing a pipe connection from the existing metal salt feed facility to the secondary treatment process to provide chemical backup for P removal in case of a process upset condition.

The cost estimate for the projects described above is presented in Table 7.2.

Table 7.2 Tier 1 Project Cost Estimate – Aeration Upgrades

Description	Cost
Total Direct Costs	$722,000
Contingency (30%)	$217,000
Subtotal	**$939,000**
General Contractor Overhead, Profit, and Risk (15%)	$141,000
Total Estimated Construction Cost	**$1,080,000**
Engineering, Legal, and Administrative Fees (15%)	$162,000
Owner's Reserve for Change Orders (5%)	$54,000
Total Estimated Project Cost	**$1,296,000**

7.4.1.2 MLR Modifications

The second project in Tier 1 includes addition of VFDs on three of the five MLR pumps and re-routing the MLR discharge to allow it to feed either the first or the second zones of the anoxic basins. Details of the recommended routing are shown in Figures 7.1 and 7.2. It is further recommended to include control upgrades to tie the MLR pumping operation to the anoxic zone effluent nitrate probe readings. The cost estimate for this project is presented in Table 7.3.

Table 7.3 Tier 1 Project Cost Estimate – MLR Modifications

Description	Cost
Total Direct Costs	$310,000
Contingency (30%)	$93,000
Subtotal	**$403,000**
General Contractor Overhead, Profit, and Risk (15%)	$60,000
Total Estimated Construction Cost	**$463,000**
Engineering, Legal, and Administrative Fees (15%)	$69,000
Owner's Reserve for Change Orders (5%)	$23,000
Total Estimated Project Cost	**$555,000**

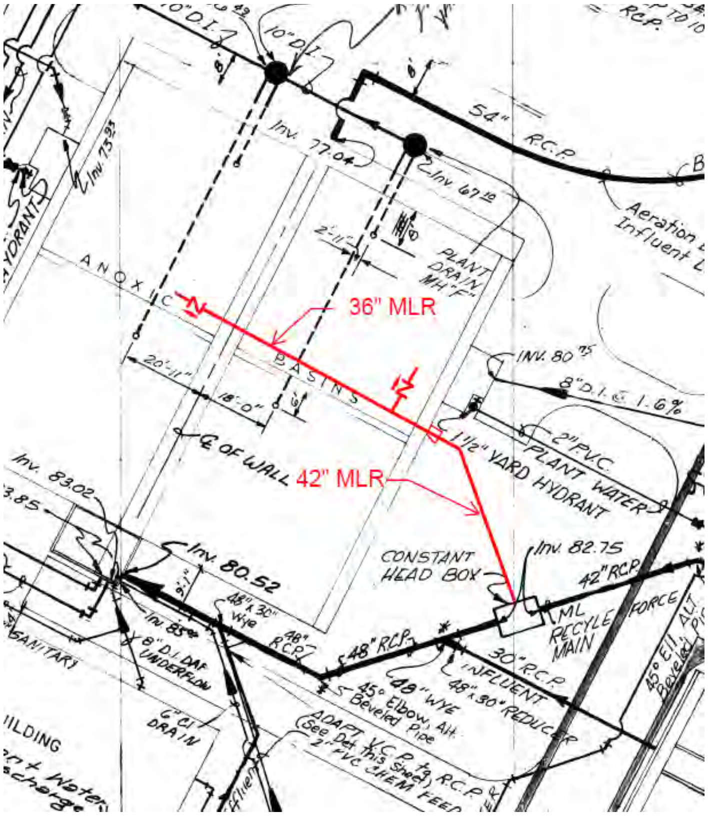


Figure 7.1 Yard Piping Modifications for MLR Modifications

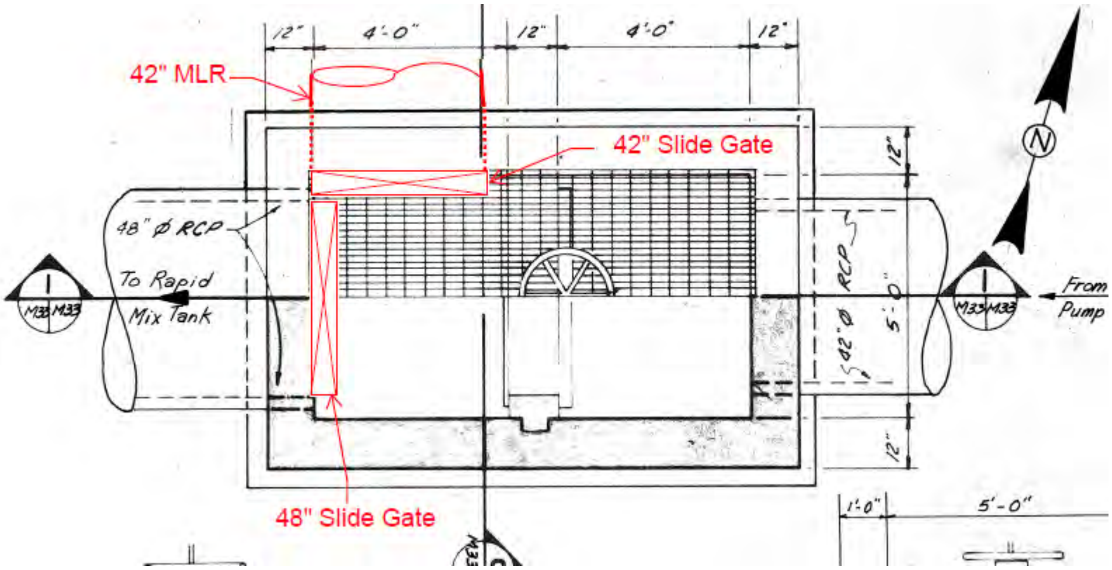


Figure 7.2 ML Splitter Box Modifications

7.4.1.3 Filtrate Equalization

The third project in Tier 1 includes addition of filtrate equalization. The filtrate equalization tank was sized to provide 3 days of storage capacity for filtrate and washwater. The current filtrate flow (average of 60,400 gallons) was projected to a future design capacity of 13 mgd and washwater flows (estimated as 30,200 gpd) were added for a total future process flow of approximately 100,000 gpd. This results in a recommended equalization tank storage volume of 300,000 gallons or 40,740 cubic feet (cu ft).

The cost estimate for this project is presented in Table 7.4.

Table 7.4 Tier 1 Project Cost Estimate – Filtrate Equalization

Description	Cost
Total Direct Costs	$953,000
Contingency (30%)	$286,000
Subtotal	**$1,239,000**
General Contractor Overhead, Profit, and Risk (15%)	$186,000
Total Estimated Construction Cost	**$1,425,000**
Engineering, Legal, and Administrative Fees (15%)	$214,000
Owner's Reserve for Change Orders (5%)	$71,000
Total Estimated Project Cost	**$1,710,000**

7.4.1.4 Sidestream Treatment

The fourth project in Tier 1 includes addition of sidestream treatment for the filtrate. The cost for sidestream treatment for P removal is based on multiple vendor quotes recently obtained for struvite sequestration systems for similar sized facilities. The cost estimate for this project is presented in Table 7.5.

Table 7.5 Tier 1 Project Cost Estimate – Sidestream Treatment

Description	Cost
Total Direct Costs	$2,802,000
Contingency (30%)	$841,000
Subtotal	**$3,643,000**
General Contractor Overhead, Profit, and Risk (15%)	$546,000
Total Estimated Construction Cost	**$4,189,000**
Engineering, Legal, and Administrative Fees (15%)	$628,000
Owner's Reserve for Change Orders (5%)	$209,000
Total Estimated Project Cost	**$5,026,000**

An overall conceptual site layout of the Tier 1 improvements is shown in Figure 7.3.

Figure 7.3 Conceptual Site Layout for Tier 1 Improvements

7.4.2 Tier 2 Recommended Projects

In order to meet Tier 2 effluent limits, Carollo recommends construction of chemical feed facilities for both ferric and carbon addition as well as new MBRs. In order to remain conservative at this conceptual level of cost estimating, it was assumed that the existing metal salt storage facility would need to be expanded to provide for additional capacity for liquid stream treatment. Ferric can be added at several locations in the treatment process, and flexibility in dosage locations should be considered during design. It was assumed that the MBR would be retrofitted into a portion of the existing secondary clarifiers (see Figure 7.4). The MBR system includes the membrane cassettes, new permeate pumps, piping for air and permeate above the membrane train tanks to the permeate pumps and air scour blowers, membrane tank covers, a new programmable logic controller (PLC), air compressors, air scour blowers and ancillary control components and instrumentation. The addition of membrane filters eliminates the need for secondary clarifiers and tertiary filtration. This could free up space on the plant site for future treatment processes. Converting to MBR also allows staff to carry higher MLSS concentrations in the aeration basins.

The cost estimate for the chemical feed facilities is presented in Table 7.6. The cost estimate for the membrane filters is presented in Table 7.7. Please note that the costs for Tier 1 projects are not included in the costs below; however, these costs assume that the Tier 1 projects have previously (or concurrently) been implemented.

Table 7.6 Tier 2 Project Cost Estimate – Chemical Feed Facilities

Description	Cost
Total Direct Costs	$2,196,000
Contingency (30%)	$659,000
Subtotal	**$2,855,000**
General Contractor Overhead, Profit, and Risk (15%)	$428,000
Total Estimated Construction Cost	**$3,283,000**
Engineering, Legal, and Administrative Fees (15%)	$492,000
Owner's Reserve for Change Orders (5%)	$164,000
Total Estimated Project Cost	**$3,939,000**

Table 7.7 Tier 2 Project Cost Estimate – Membrane Bioreactor Filters

Description	Cost
Total Direct Costs	$17,321,000
Contingency (30%)	$5,196,000
Subtotal	**$17,321,000**
General Contractor Overhead, Profit, and Risk (15%)	$3,378,000
Total Estimated Construction Cost	**$25,895,000**
Engineering, Legal, and Administrative Fees (15%)	$3,884,000
Owner's Reserve for Change Orders (5%)	$1,295,000
Total Estimated Project Cost	**$31,074,000**

An overall conceptual site layout of the Tier 2 improvements is shown in Figure 7.4.

Figure 7.4 Conceptual Site Layout for Tier 2 Improvements

7.4.3 Tier 3 Recommended Projects

In order to meet Tier 3 effluent limits, Carollo recommends construction of construction of chemical feed facilities for both ferric and carbon addition and construction of new tertiary deep bed media filters for N and P removal. Carbon will be fed to the denitrification filters for removal of nitrate residuals and metal salt will be added to the subsequent P removal filters. As discussed above, it was assumed that modifications will be required to the existing chemical feed building. It was also assumed that the filters will be built offline to the existing tertiary filtration facility to accommodate construction phasing while keeping the facility in operation. The cost for the chemical feed facilities is shown under Tier 2 in Table 7.6. The cost estimate for the tertiary filters is presented in Table 7.8. Please note that the costs for Tier 1 projects are not included in the costs below; however, these costs assume that the Tier 1 projects have previously (or concurrently) been implemented.

Table 7.8 Tier 3 Project Cost Estimate – Tertiary Filters

Description	Cost
Total Direct Costs	$8,071,000
Contingency (30%)	$2,421,000
Subtotal	**$10,492,000**
General Contractor Overhead, Profit, and Risk (15%)	$1,574,000
Total Estimated Construction Cost	**$12,066,000**
Engineering, Legal, and Administrative Fees (15%)	$1,810,000
Owner's Reserve for Change Orders (5%)	$603,000
Total Estimated Project Cost	**$14,479,000**

An overall conceptual site layout of the Tier 3 improvements is shown in Figure 7.5.

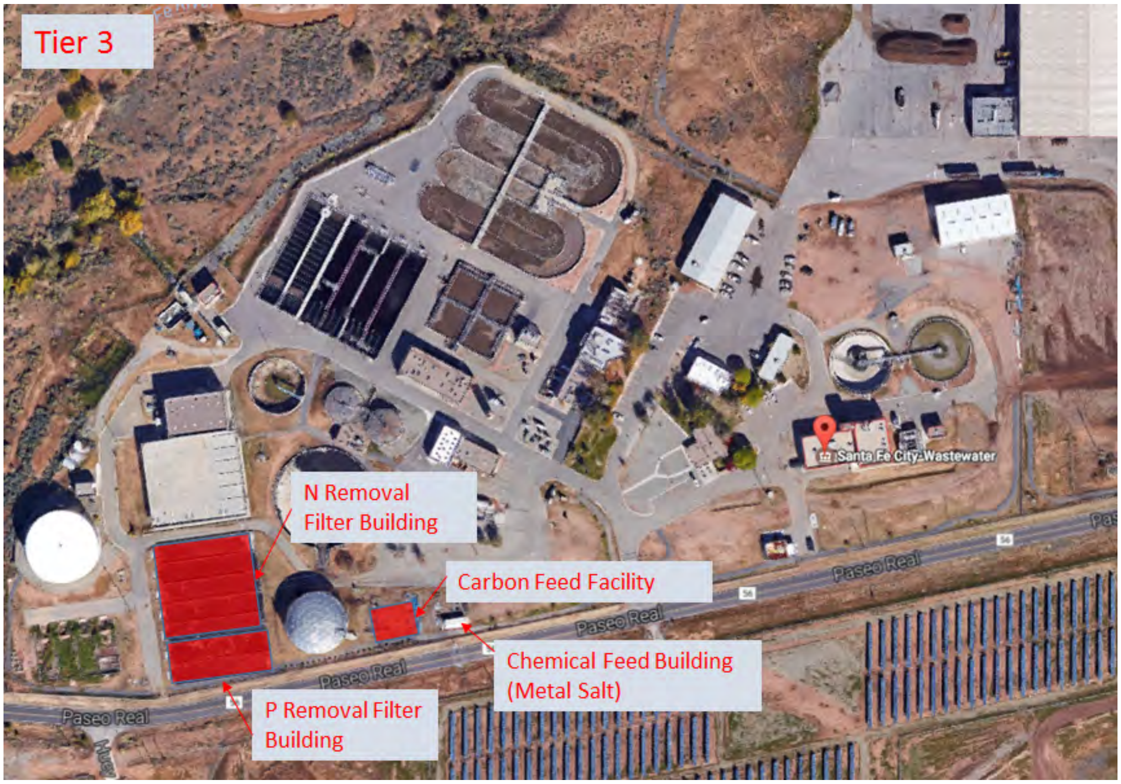


Figure 7.5 Conceptual Site Layout for Tier 3 Improvements

7.4.4 Tier 4 Recommended Projects

In order to meet Tier 4 effluent limits, construction of a microfiltration/reverse osmosis system is required downstream of the secondary clarifiers. This system will include membrane feed and permeate pumps, I&C components, as well as chemicals for clean-in-place and post-treatment water conditioning. The equipment can be located inside the existing filtration building. It should be noted that this alternative will significantly increase the power costs at the PR WWTP.

Brine disposal from reverse osmosis systems can be a technical and permitting challenge in inland locations. So-called "zero liquid discharge" systems do not yet exist in full-scale operations in New Mexico and stream discharge permitting for brine streams has been proven extremely challenging for utilities in other states, such as Colorado. Deep well injection, while driving significant capital and operation and maintenance (O&M) costs, has been proven to be a viable option in the Front Range in Colorado for disposal of brine streams at this time. Brine disposal and management technologies are in development in the industry and other alternatives may become cost effective and feasible in the future. For purposes of capital improvement, planning costs estimates presented herein are based on deep well injection, as there is full-scale precedence for this application in the State of Colorado.

For purposes of comparison, the East Cherry Creek Valley Water and Sanitation District (ECCV) in Colorado operates a 10-mgd reverse osmosis potable water treatment facility with very high recovery rates generally exceeding 93 percent (with generation of correspondingly low brine flow rates). The plant's single deep-well injection system is estimated by ECCV staff to have cost between $3 and $4 million when installed in 2006, including drilling the deep well onsite, high-pressure pumping equipment, and high-pressure lines conveying the brine to the deep well. The deep well is approximately 10,000 feet deep and the pumping/injection system has a design pressure of 1,400 pounds per square inch (psi). Assuming a suitable deep well could be located on-site at the PR WWTF, costs for the deep well system could be higher than the ECCV system because (despite lower plant flow rates), the recovery rate would likely be lower and brine generation rates would thus be higher.

The cost estimate for this project is presented in Table 7.9. Please note that this alternative would not require the implementation of Tier 1 projects, as is the case for Tiers 2 and 3.

Table 7.9 Tier 4 Project Cost Estimate

Description	Cost
Total Direct Costs	$48,321,000
Contingency (30%)	$14,496,000
Subtotal	**$62,817,000**
General Contractor Overhead, Profit, and Risk (15%)	$9,423,000
Total Estimated Construction Cost	**$72,240,000**
Engineering, Legal, and Administrative Fees (15%)	$10,836,000
Owner's Reserve for Change Orders (5%)	$3,612,000
Total Estimated Project Cost	**$86,688,000**

An overall conceptual site layout of the Tier 4 improvements is shown in Figure 7.6.

Figure 7.6 Conceptual Site Layout for Tier 4 Improvements

7.4.5 Summary of Project Costs

A summary of the project costs for each tier is presented in Table 7.10.

Table 7.10 Project Cost Summary

Tier/Project	Cost
Tier 1 – Aeration Upgrades	$1,296,000
Tier 1 – MLR Modifications	$555,000
Tier 1 – Filtrate Equalization	$1,710,000
Tier 1 – Sidestream Treatment	$5,026,000
Tier 1 Total	**$8,587,000**
Tier 2 – Chemical Facilities	$3,939,000
Tier 2 – Membrane Filtration	$31,074,000
Tier 2 Total	**$35,013,000**
Tier 3 – Chemical Facilities	$3,939,000
Tier 3 – Tertiary Filtration	$14,479,000
Tier 3 Total	**$18,418,000**
Tier 4 – Membrane Filtration/Reverse Osmosis	$86,688,000
Tier 4 Total	**$86,688,000**

Figure 7.7 presents a graphical summary of costs for each effluent tier, and the respective effluent N and P concentrations that can be expected to be achieved. The costs for Tier 1 projects were added to Tiers 2 and 3 for comparison. Tier 1 projects are not required for Tier 4.

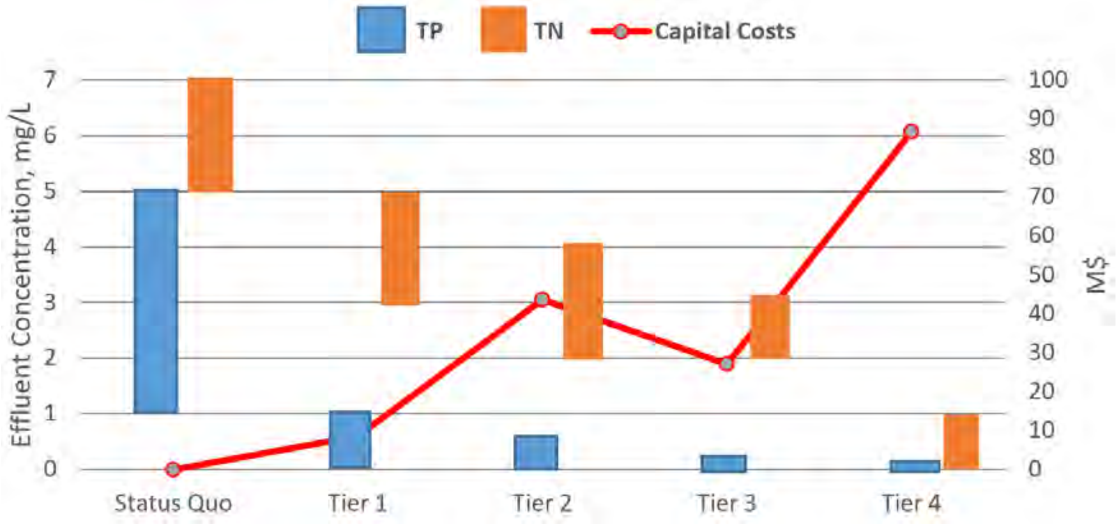


Figure 7.7 Summary of Project Costs

7.4.6 Regional Water Resource Planning

As part of a separate project, Carollo and the City of Santa Fe are evaluating alternatives to bypass a portion of the PR WWTP effluent directly to the Rio Grande, bypassing the Santa Fe River. If this were to be implemented, the PR WWTP would only need to discharge a portion of their flow to the Santa Fe River, and could realize capital cost savings on the additional unit processes described in Tiers 2 through 4. This assumes that the bypass pumping system has sufficient redundancy to reliably bypass a portion of PR WWTP's effluent. The bypass would not typically be operational during summer months due to non-potable water demands.

As an example, a reasonable scenario assumes implementation of Tier 3 improvements (e.g., chemical facilities and tertiary filtration) to achieve effluent TP of less than 0.2 mg/L and effluent TN of 2 to 3 mg/L. Assuming that 4.5 mgd of flow can be bypassed to the Rio Grande, the new facilities at the PR WWTP could be downsized from 13 mgd to an assumed 8.5 mgd. Table 7.11 presents updated costs for these downsized facilities under the given example.

Table 7.11 Tier 3 Cost Summary with Rio Grande Bypass

Tier/Project	Cost
Tier 3 – Chemical Facilities	$3,545,000
Tier 3 – Tertiary Filtration	$9,449,000
Tier 3 Total (with flow bypass)	**$12,994,000**

Appendix A

BioWin PROCESS MODEL CALIBRATION REPORT

BioWin user and configuration data

Project details

Project name: Santa Fe Paseo Real Nutrient Removal & Optimization Project ref.: 10515A00

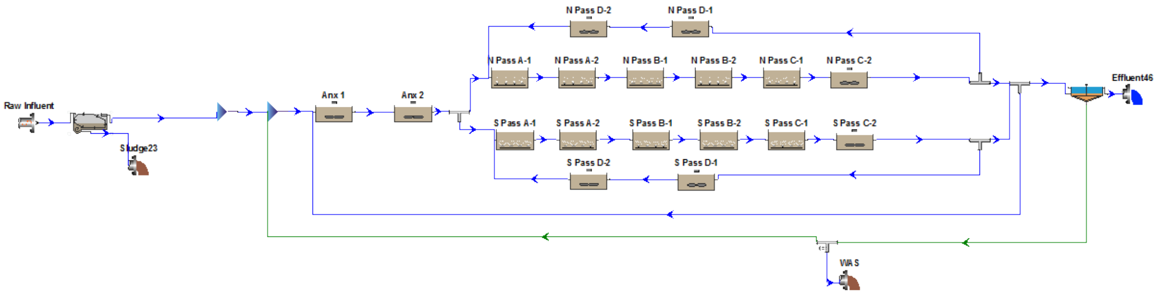
Plant name: Paseo Real User name: TRW

Created: 1/6/2017 Saved: 7/22/2017

Target SRT: 10.00 days SRT: ** days**

Average Temperature: 19.8°C

Flowsheet



Configuration information for all Ideal primary settling tank units

Physical data

Element name	Volume [Mil. Gal]	Area [ft2]	Depth [ft]
Primary Clarifiers (2/2)	0.5450	6939.0000	10.500

Operating data Average (flow/time weighted as required)

Element name	Split method	Average Split specification
Primary Clarifiers (2/2)	Flowrate [Under]	0.0135150131147541

Element name	Percent removal	Blanket fraction
Primary Clarifiers (2/2)	35.15	0.10

Configuration information for all Bioreactor units

Physical data

Element name	Volume [Mil. Gal]	Area [ft2]	Depth [ft]
Anx 1	0.6499	5329.9999	16.300
Anx 2	0.6499	5329.9999	16.300
N Pass A-2	0.4700	3861.7004	16.270
N Pass B-1	0.3050	2505.9970	16.270
N Pass B-2	0.4700	3861.7004	16.270
N Pass C-1	0.6100	5011.9941	16.270
N Pass C-2	0.4700	3861.7004	16.270
N Pass D-1	0.6100	5011.9941	16.270
N Pass D-2	0.5200	4272.5195	16.270
N Pass A-1	0.3050	2505.9970	16.270
S Pass A-1	0.3050	2505.9970	16.270
S Pass A-2	0.4700	3861.7004	16.270
S Pass B-1	0.3050	2505.9970	16.270
S Pass B-2	0.4700	3861.7004	16.270
S Pass C-1	0.3050	2505.9970	16.270
S Pass C-2	0.4700	3861.7004	16.270
S Pass D-1	0.6100	5011.9941	16.270
S Pass D-2	0.5200	4272.5195	16.270

Operating data Average (flow/time weighted as required)

Element name	Average DO Setpoint [mg/L]
Anx 1	0
Anx 2	0
N Pass A-2	2.0
N Pass B-1	1.1
N Pass B-2	0.3
N Pass C-1	0.1
N Pass C-2	0
N Pass D-1	0
N Pass D-2	0
N Pass A-1	2.0
S Pass A-1	2.0
S Pass A-2	2.0
S Pass B-1	1.7
S Pass B-2	0.3
S Pass C-1	0.1
S Pass C-2	0
S Pass D-1	0
S Pass D-2	0

Aeration equipment parameters

Configuration information for all Effluent units

Configuration information for all Ideal clarifier units

Physical data

Element name	Volume[Mil. Gal]	Area[ft2]	Depth[ft]
Secondary Clarifiers (6/6)	2.5637	3.264E+4	10.500

Operating data Average (flow/time weighted as required)

Element name	Split method	Average Split specification
Secondary Clarifiers (6/6)	Flowrate [Under]	5.39890491803278

Element name	Average Temperature	Reactive	Percent removal	Blanket fraction
Secondary Clarifiers (6/6)	Uses global setting	No	99.85	0.05

Configuration information for all COD Influent units

Operating data Average (flow/time weighted as required)

Element name	Raw Influent
Flow	5.02598400655738
Total COD mgCOD/L	889.25
Total Kjeldahl Nitrogen mgN/L	81.55
Total P mgP/L	15.20
Nitrate N mgN/L	0
pH	7.07
Alkalinity mmol/L	255.40
ISS Influent mgISS/L	35.25
Calcium mg/L	80.00
Magnesium mg/L	15.00
Dissolved O2 mg/L	0

Element name	Raw Influent
Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]	0.2000
Fac - Acetate [gCOD/g of readily biodegradable COD]	0.3470
Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]	0.4000
Fus - Unbiodegradable soluble [gCOD/g of total COD]	0.0300
Fup - Unbiodegradable particulate [gCOD/g of total COD]	0.3000
Fna - Ammonia [gNH3-N/gTKN]	0.7700
Fnox - Particulate organic nitrogen [gN/g Organic N]	0.5000
Fnus - Soluble unbiodegradable TKN [gN/gTKN]	0.0200
FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]	0.0350
Fpo4 - Phosphate [gPO4-P/gTP]	0.6320
FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]	0.0110
FZbh - OHO COD fraction [gCOD/g of total COD]	0.0900
FZbm - Methylotroph COD fraction [gCOD/g of total COD]	1.000E-4
FZaob - AOB COD fraction [gCOD/g of total COD]	1.000E-4
FZnob - NOB COD fraction [gCOD/g of total COD]	1.000E-4
FZaao - AAO COD fraction [gCOD/g of total COD]	1.000E-4
FZbp - PAO COD fraction [gCOD/g of total COD]	1.000E-4
FZbpa - Propionic acetogens COD fraction [gCOD/g of total COD]	1.000E-4
FZbam - Acetoclastic methanogens COD fraction [gCOD/g of total COD]	1.000E-4
FZbhm - H2-utilizing methanogens COD fraction [gCOD/g of total COD]	1.000E-4
FZe - Endogenous products COD fraction [gCOD/g of total COD]	0

Configuration information for all General Mixer units

Configuration information for all Splitter units

Operating data Average (flow/time weighted as required)

Element name	Split method	Average Split specification
Splitter59	Flowrate [Side]	0.286174497049181
Splitter12	Flow paced	50.00 %
Splitter11	Flowrate [Side]	19.7471049180328
Splitter32	Fraction	0.50
Splitter48	Flow paced	50.00 %

BioWin Album

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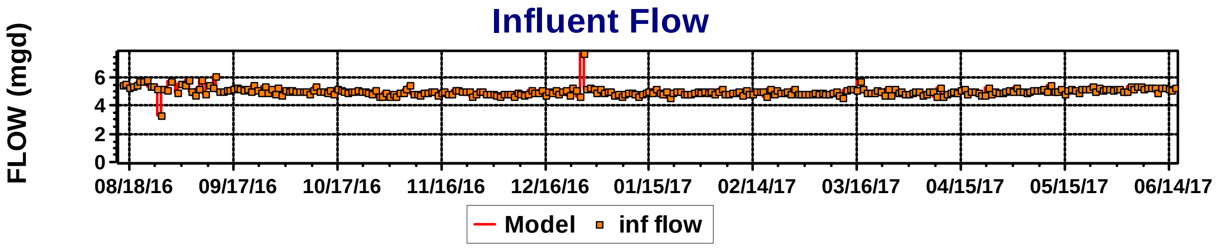

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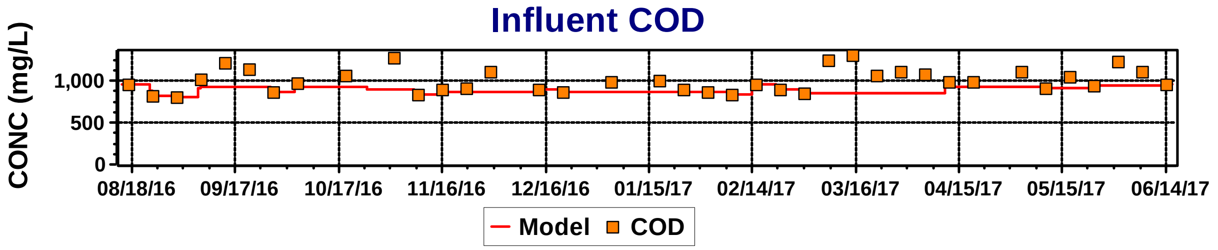

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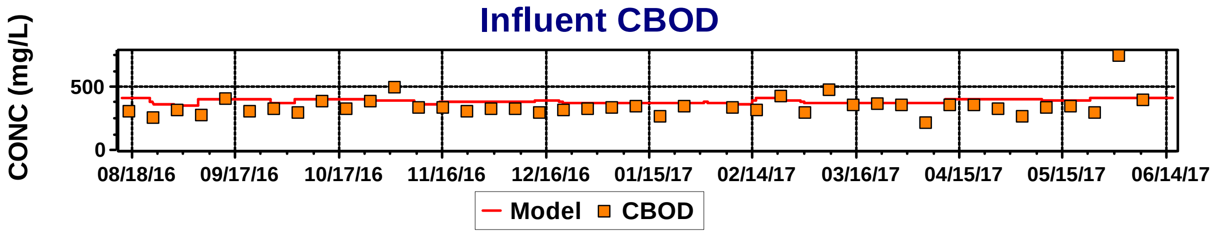

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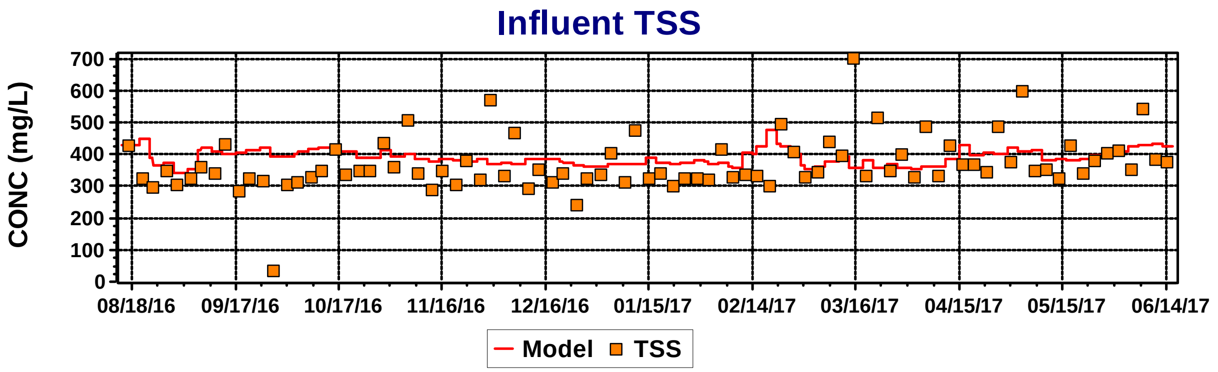

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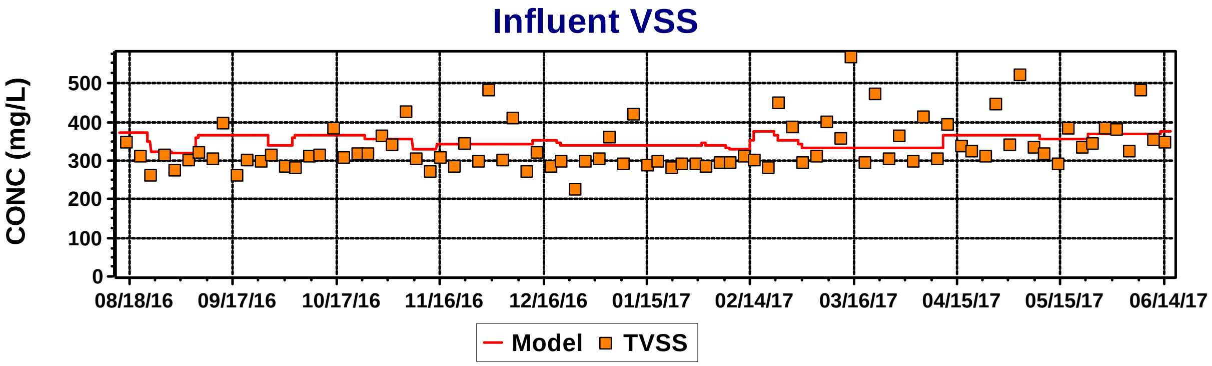

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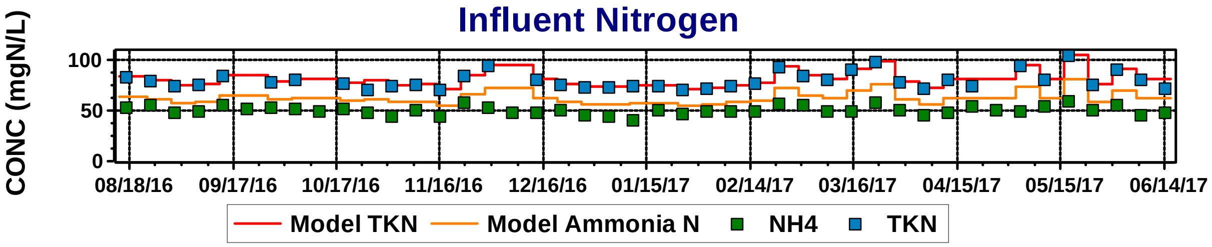

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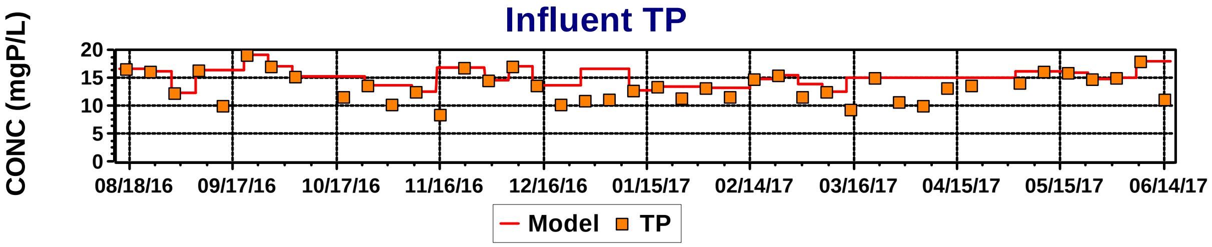

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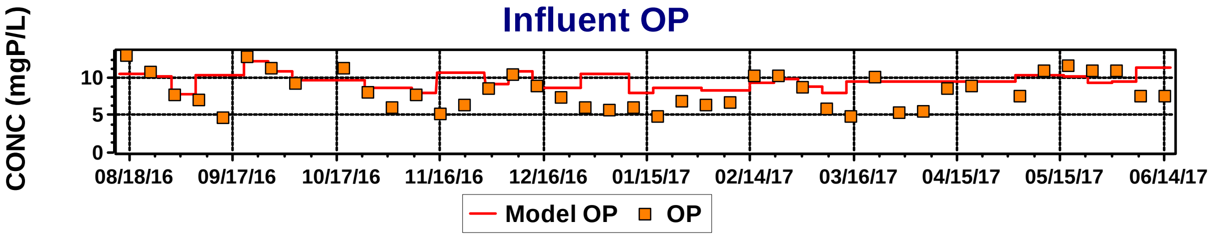

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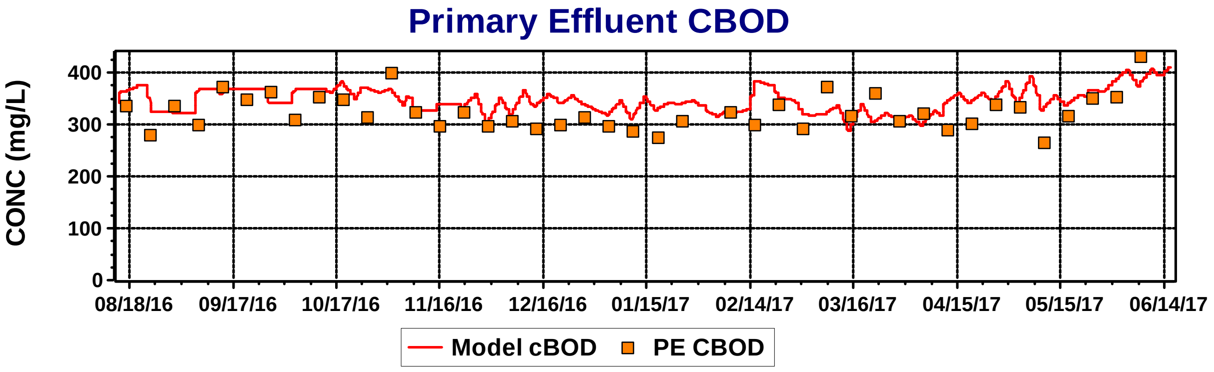

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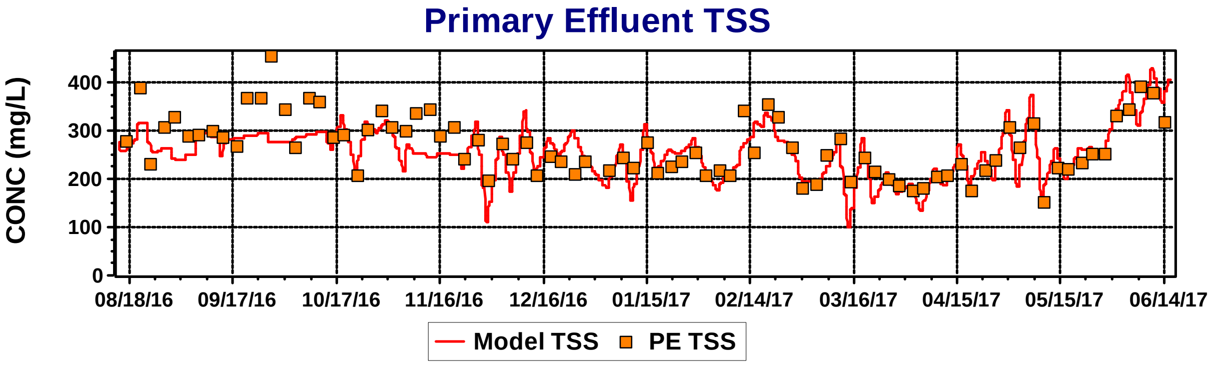

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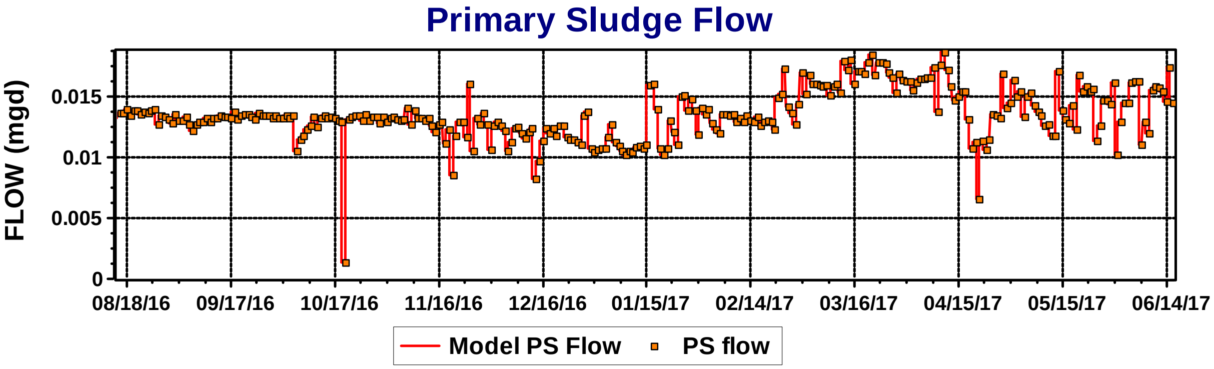

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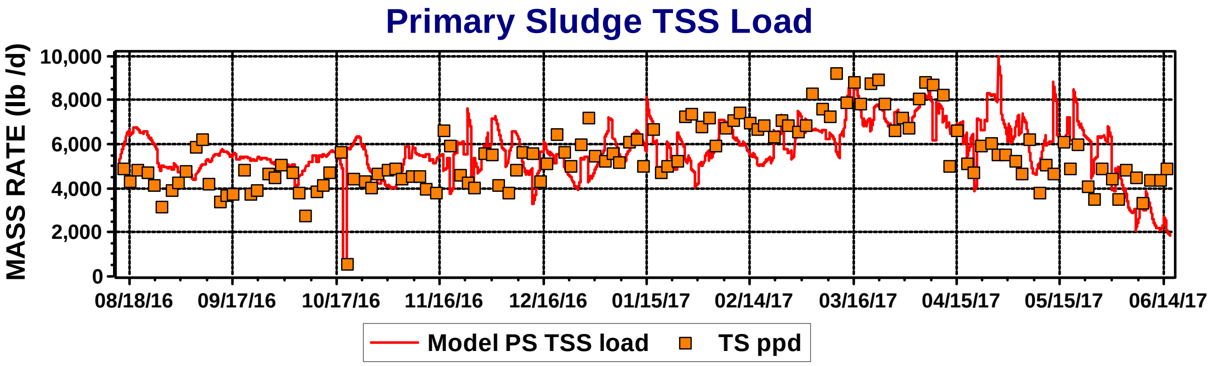

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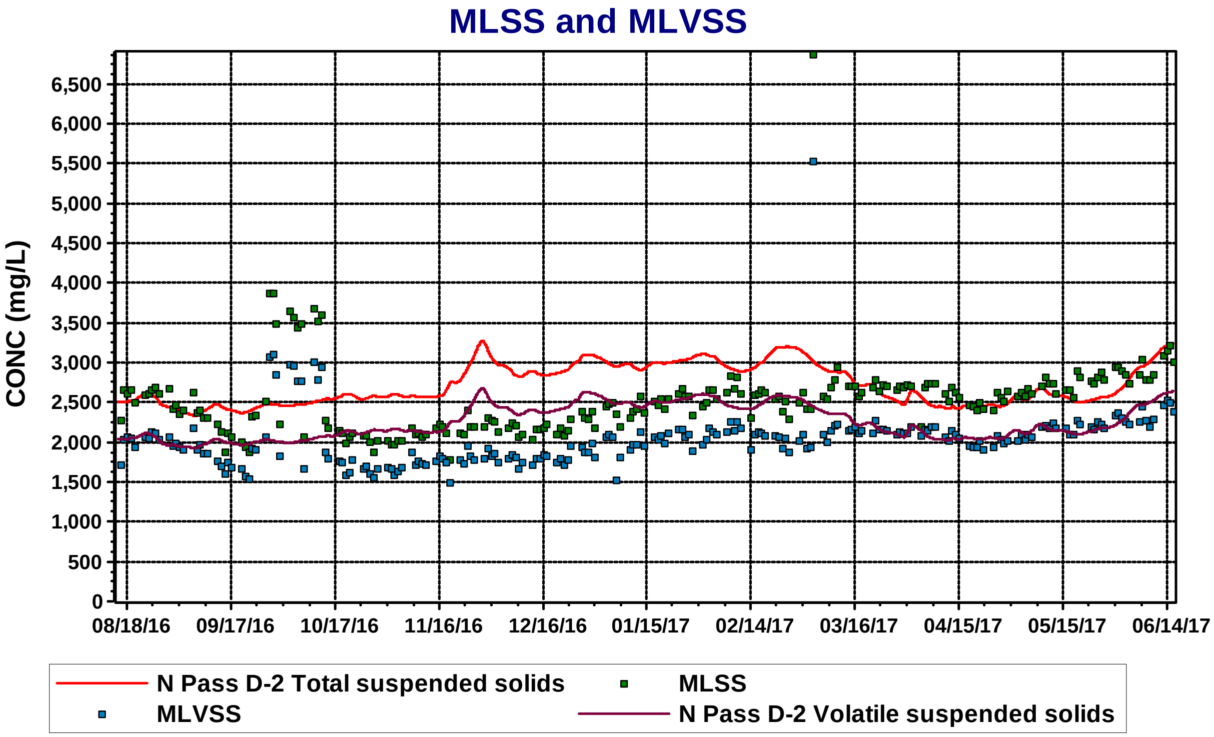

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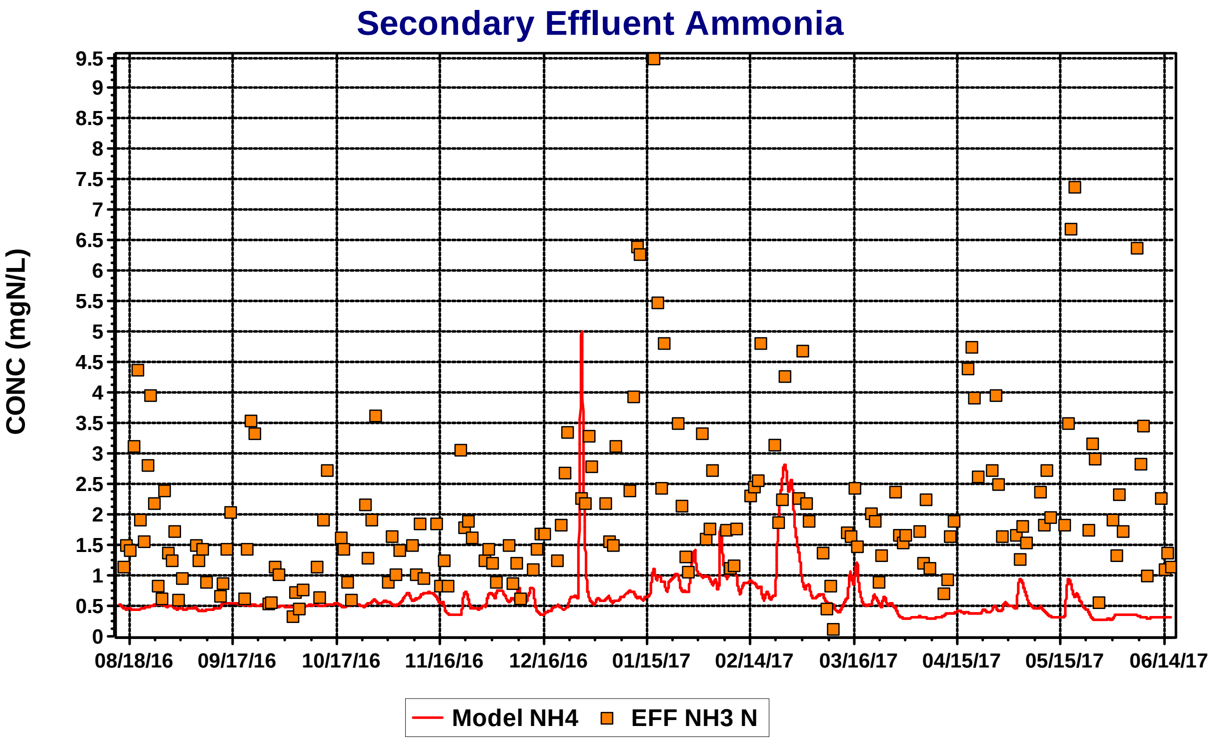

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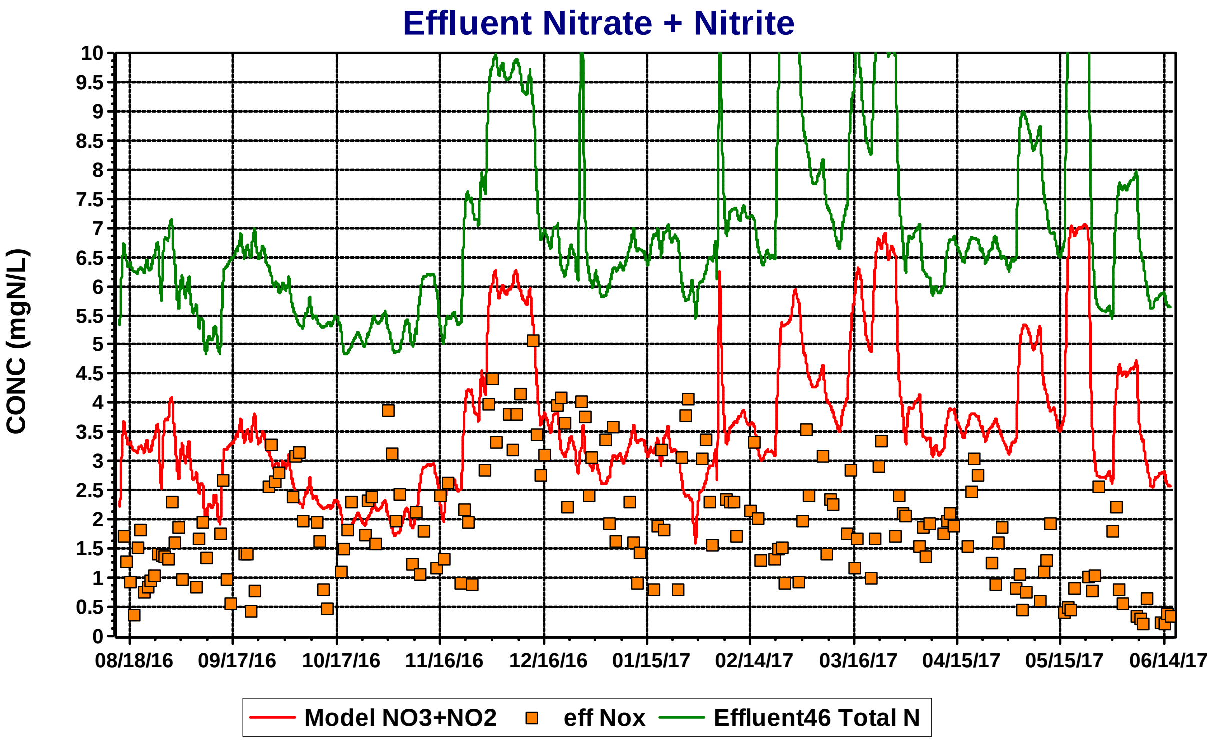

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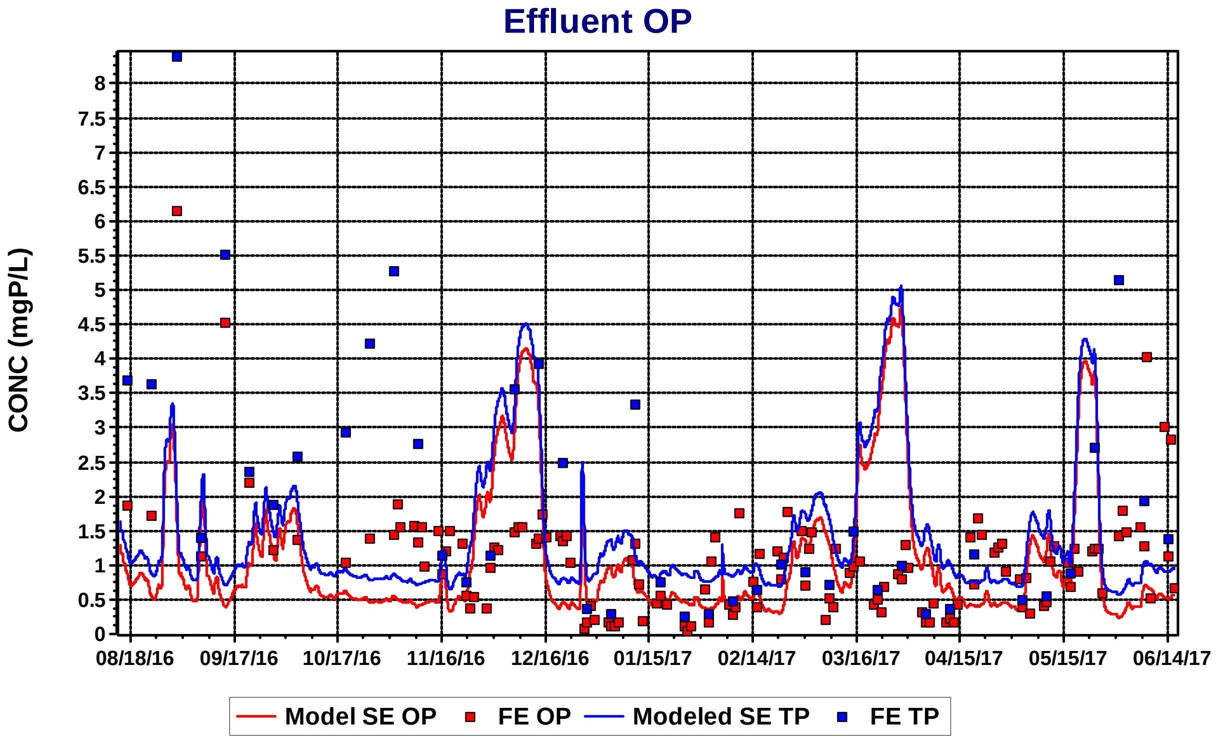

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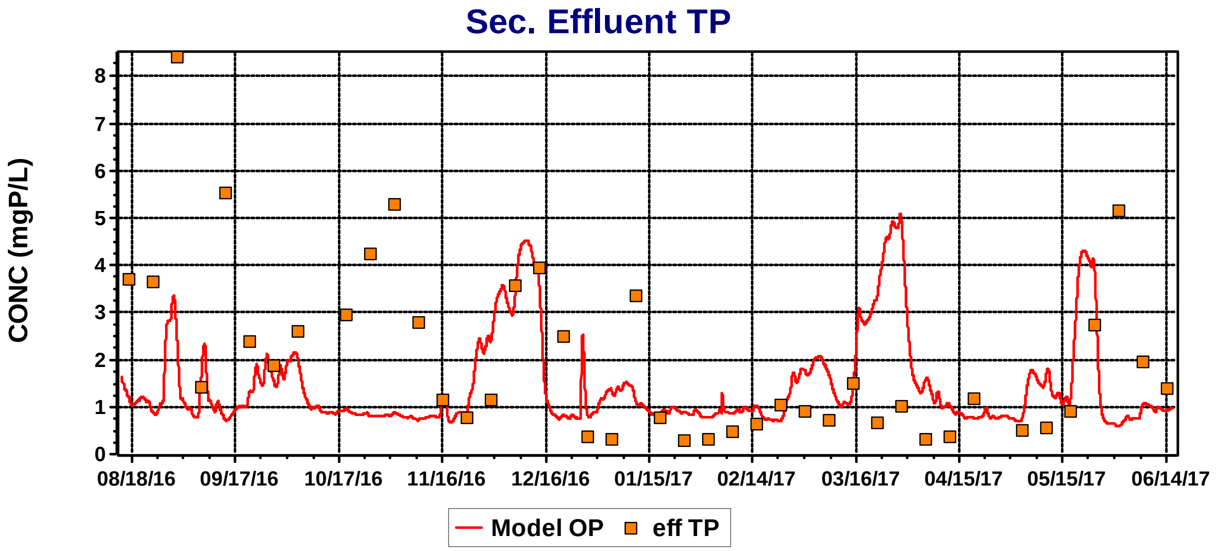

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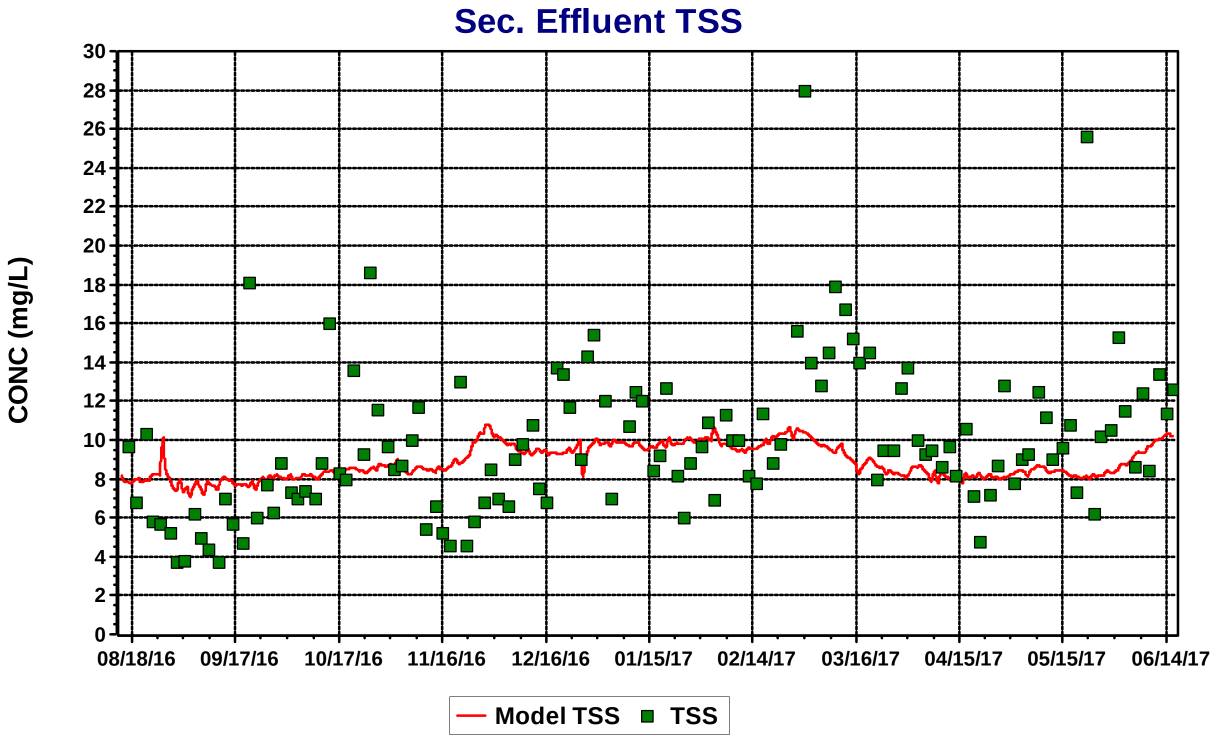

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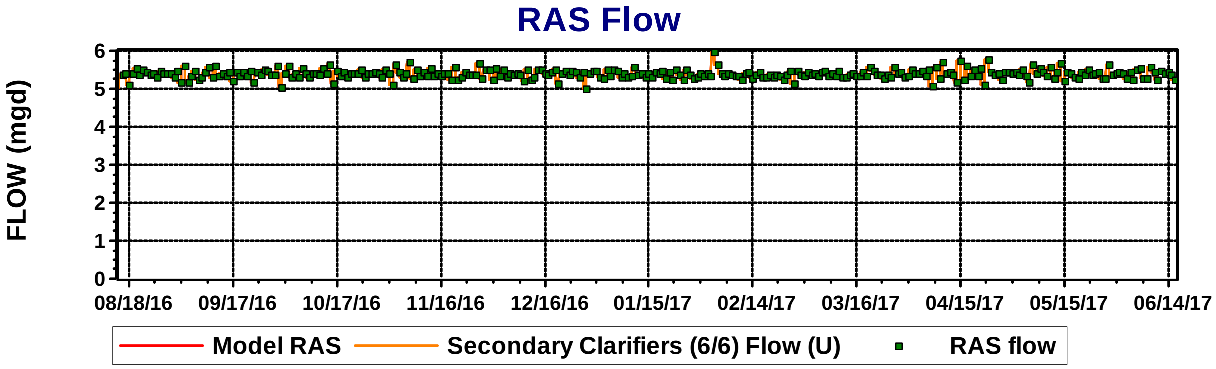

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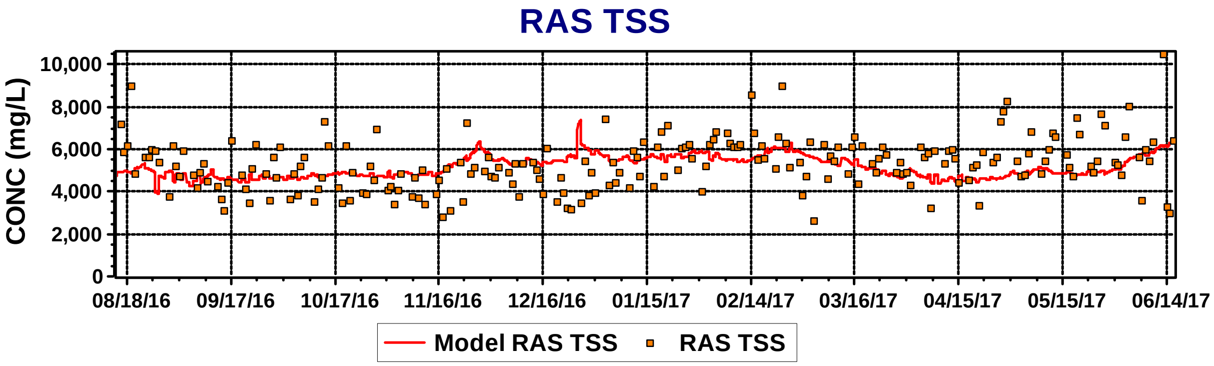

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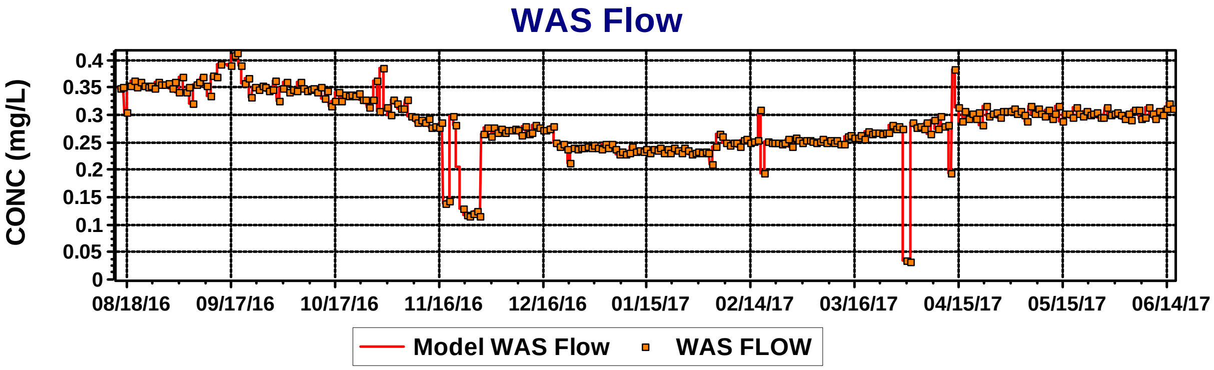

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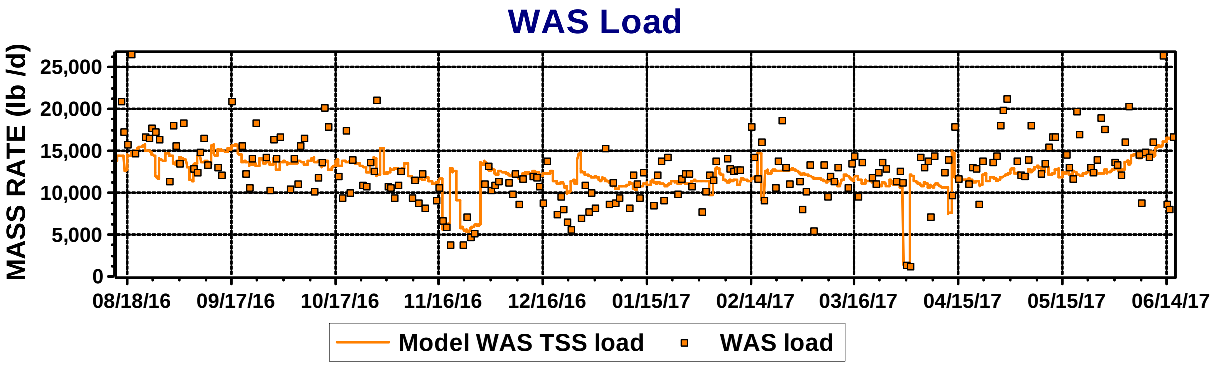

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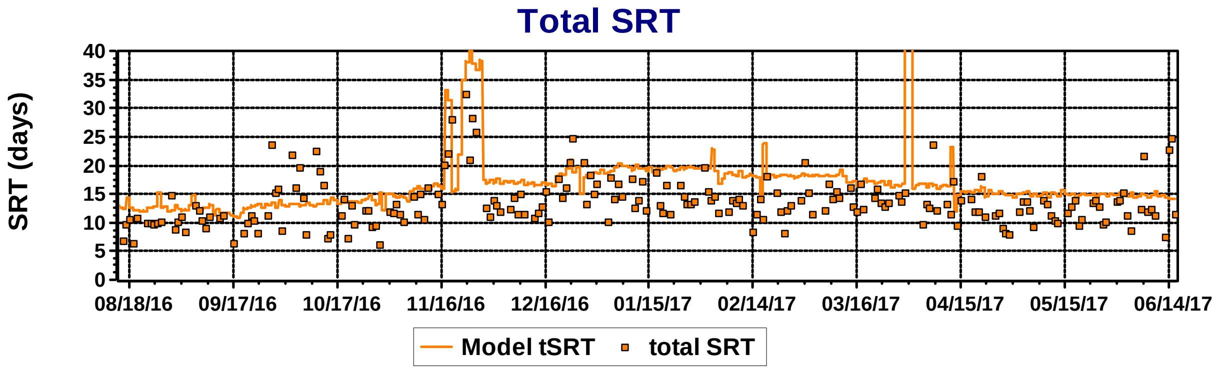

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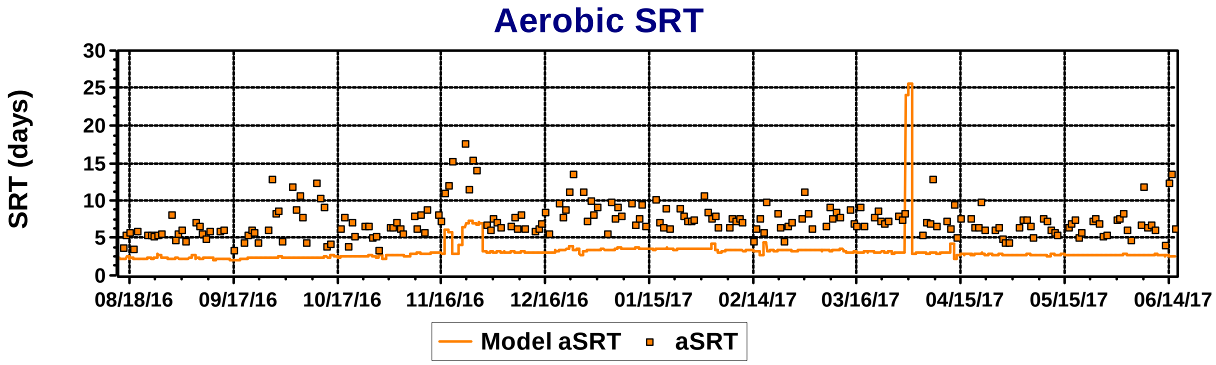

Global Parameters

Common

Name	Default	Value	
Hydrolysis rate [1/d]	2.1000	2.1000	1.0290
Hydrolysis half sat. [-]	0.0600	0.0600	1.0000
Anoxic hydrolysis factor [-]	0.2800	0.2800	1.0000
Anaerobic hydrolysis factor (AS) [-]	0.0400	0.0400	1.0000
Anaerobic hydrolysis factor (AD) [-]	0.5000	0.5000	1.0000
Adsorption rate of colloids [L/(mgCOD d)]	0.1500	0.1500	1.0290
Ammonification rate [L/(mgCOD d)]	0.0800	0.0800	1.0290
Assimilative nitrate/nitrite reduction rate [1/d]	0.5000	0.5000	1.0000
Endogenous products decay rate [1/d]	0	0	1.0000

AOB

Name	Default	Value	
Max. spec. growth rate [1/d]	0.9000	0.9000	1.0720
Substrate (NH4) half sat. [mgN/L]	0.7000	0.7000	1.0000
Byproduct NH4 logistic slope [-]	50.0000	50.0000	1.0000
Byproduct NH4 inflection point [mgN/L]	1.4000	1.4000	1.0000
AOB denite DO half sat. [mg/L]	0.1000	0.1000	1.0000
AOB denite HNO2 half sat. [mgN/L]	5.000E-6	5.000E-6	1.0000
Aerobic decay rate [1/d]	0.1700	0.1700	1.0290
Anoxic/anaerobic decay rate [1/d]	0.0800	0.0800	1.0290
KiHNO2 [mmol/L]	0.0050	0.0050	1.0000

NOB

Name	Default	Value	
Max. spec. growth rate [1/d]	0.7000	0.7000	1.0600
Substrate (NO2) half sat. [mgN/L]	0.1000	0.1000	1.0000
Aerobic decay rate [1/d]	0.1700	0.1700	1.0290
Anoxic/anaerobic decay rate [1/d]	0.0800	0.0800	1.0290
KiNH3 [mmol/L]	0.0750	0.0750	1.0000

AAO

Name	Default	Value	
Max. spec. growth rate [1/d]	0.2000	0.2000	1.1000
Substrate (NH4) half sat. [mgN/L]	2.0000	2.0000	1.0000
Substrate (NO2) half sat. [mgN/L]	1.0000	1.0000	1.0000
Aerobic decay rate [1/d]	0.0190	0.0190	1.0290
Anoxic/anaerobic decay rate [1/d]	0.0095	0.0095	1.0290
Ki Nitrite [mgN/L]	1000.0000	1000.0000	1.0000
Nitrite sensitivity constant [L / (d mgN)]	0.0160	0.0160	1.0000

OHO

Name	Default	Value	
Max. spec. growth rate [1/d]	3.2000	3.2000	1.0290
Substrate half sat. [mgCOD/L]	5.0000	5.0000	1.0000
Anoxic growth factor [-]	0.5000	0.5000	1.0000
Denite N2 producers (NO3 or NO2) [-]	0.5000	0.5000	1.0000
Aerobic decay rate [1/d]	0.6200	0.6200	1.0290
Anoxic decay rate [1/d]	0.2330	0.2330	1.0290
Anaerobic decay rate [1/d]	0.1310	0.1310	1.0290
Fermentation rate [1/d]	1.6000	1.6000	1.0290
Fermentation half sat. [mgCOD/L]	5.0000	5.0000	1.0000
Fermentation growth factor (AS) [-]	0.2500	0.2500	1.0000
Free nitrous acid inhibition [mol/L]	1.000E-7	1.000E-7	1.0000

Methylotrophs

Name	Default	Value	
Max. spec. growth rate [1/d]	1.3000	1.3000	1.0720
Methanol half sat. [mgCOD/L]	0.5000	0.5000	1.0000
Denite N2 producers (NO3 or NO2) [-]	0.5000	0.5000	1.0000
Aerobic decay rate [1/d]	0.0400	0.0400	1.0290
Anoxic/anaerobic decay rate [1/d]	0.0300	0.0300	1.0290
Free nitrous acid inhibition [mmol/L]	1.000E-7	1.000E-7	1.0000

PAO

Name	Default	Value	
Max. spec. growth rate [1/d]	**0.9500**	**0.8500**	1.0000
Max. spec. growth rate, P-limited [1/d]	0.4200	0.4200	1.0000
Substrate half sat. [mgCOD(PHB)/mgCOD(Zbp)]	0.1000	0.1000	1.0000
Substrate half sat., P-limited [mgCOD(PHB)/mgCOD(Zbp)]	0.0500	0.0500	1.0000
Magnesium half sat. [mgMg/L]	0.1000	0.1000	1.0000
Cation half sat. [mmol/L]	0.1000	0.1000	1.0000
Calcium half sat. [mgCa/L]	0.1000	0.1000	1.0000
Aerobic/anoxic decay rate [1/d]	0.1000	0.1000	1.0000
Aerobic/anoxic maintenance rate [1/d]	0	0	1.0000
Anaerobic decay rate [1/d]	0.0400	0.0400	1.0000
Anaerobic maintenance rate [1/d]	0	0	1.0000
Sequestration rate [1/d]	4.5000	4.5000	1.0000
Anoxic growth factor [-]	0.3300	0.2700	1.0000

Acetogens

Name	Default	Value	
Max. spec. growth rate [1/d]	0.2500	0.2500	1.0290
Substrate half sat. [mgCOD/L]	10.0000	10.0000	1.0000
Acetate inhibition [mgCOD/L]	10000.0000	10000.0000	1.0000
Anaerobic decay rate [1/d]	0.0500	0.0500	1.0290
Aerobic/anoxic decay rate [1/d]	0.5200	0.5200	1.0290

Methanogens

Name	Default	Value	
Acetoclastic max. spec. growth rate [1/d]	0.3000	0.3000	1.0290
H2-utilizing max. spec. growth rate [1/d]	1.4000	1.4000	1.0290
Acetoclastic substrate half sat. [mgCOD/L]	100.0000	100.0000	1.0000
Acetoclastic methanol half sat. [mgCOD/L]	0.5000	0.5000	1.0000
H2-utilizing CO2 half sat. [mmol/L]	0.1000	0.1000	1.0000
H2-utilizing substrate half sat. [mgCOD/L]	1.0000	1.0000	1.0000
H2-utilizing methanol half sat. [mgCOD/L]	0.5000	0.5000	1.0000
Acetoclastic propionic inhibition [mgCOD/L]	10000.0000	10000.0000	1.0000
Acetoclastic anaerobic decay rate [1/d]	0.1300	0.1300	1.0290
Acetoclastic aerobic/anoxic decay rate [1/d]	0.6000	0.6000	1.0290
H2-utilizing anaerobic decay rate [1/d]	0.1300	0.1300	1.0290
H2-utilizing aerobic/anoxic decay rate [1/d]	2.8000	2.8000	1.0290

pH

Name	Default	Value
OHO low pH limit [-]	4.0000	4.0000
OHO high pH limit [-]	10.0000	10.0000
Methylotrophs low pH limit [-]	4.0000	4.0000
Methylotrophs high pH limit [-]	10.0000	10.0000
Autotrophs low pH limit [-]	5.5000	5.5000
Autotrophs high pH limit [-]	9.5000	9.5000
PAO low pH limit [-]	4.0000	4.0000
PAO high pH limit [-]	10.0000	10.0000
OHO low pH limit (anaerobic) [-]	5.5000	5.5000
OHO high pH limit (anaerobic) [-]	8.5000	8.5000
Propionic acetogens low pH limit [-]	4.0000	4.0000
Propionic acetogens high pH limit [-]	10.0000	10.0000
Acetoclastic methanogens low pH limit [-]	5.0000	5.0000
Acetoclastic methanogens high pH limit [-]	9.0000	9.0000
H2-utilizing methanogens low pH limit [-]	5.0000	5.0000
H2-utilizing methanogens high pH limit [-]	9.0000	9.0000

Switches

Name	Default	Value
OHO DO half sat. [mgO2/L]	**0.0500**	**0.3000**
PAO DO half sat. [mgO2/L]	0.0500	0.0500
Anoxic/anaerobic NOx half sat. [mgN/L]	0.1500	0.1500
AOB DO half sat. [mgO2/L]	0.2500	0.2500
NOB DO half sat. [mgO2/L]	0.5000	0.5000
AAO DO half sat. [mgO2/L]	0.0100	0.0100
Anoxic NO3(->NO2) half sat. [mgN/L]	0.1000	0.1000
Anoxic NO3(->N2) half sat. [mgN/L]	0.0500	0.0500
Anoxic NO2(->N2) half sat. (mgN/L)	0.0100	0.0100
NH3 nutrient half sat. [mgN/L]	0.0050	0.0050
PolyP half sat. [mgP/mgCOD]	0.0100	0.0100
VFA sequestration half sat. [mgCOD/L]	5.0000	5.0000
P uptake half sat. [mgP/L]	0.1500	0.1500
P nutrient half sat. [mgP/L]	0.0010	0.0010
Autotroph CO2 half sat. [mmol/L]	0.1000	0.1000
H2 low/high half sat. [mgCOD/L]	1.0000	1.0000
Propionic acetogens H2 inhibition [mgCOD/L]	5.0000	5.0000
Synthesis anion/cation half sat. [meq/L]	0.0100	0.0100

Common

Name	Default	Value
Biomass volatile fraction (VSS/TSS)	0.9200	0.9200
Endogenous residue volatile fraction (VSS/TSS)	0.9200	0.9200
N in endogenous residue [mgN/mgCOD]	0.0700	0.0700
P in endogenous residue [mgP/mgCOD]	0.0220	0.0220
Endogenous residue COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200
Particulate substrate COD:VSS ratio [mgCOD/mgVSS]	**1.6000**	**1.3700**
Particulate inert COD:VSS ratio [mgCOD/mgVSS]	**1.6000**	**1.3700**
Molecular weight of other anions [mg/mmol]	35.5000	35.5000
Molecular weight of other cations [mg/mmol]	39.1000	39.1000

AOB

Name	Default	Value
Yield [mgCOD/mgN]	0.1500	0.1500
AOB denite NO2 fraction as TEA [-]	0.5000	0.5000
Byproduct NH4 fraction to N2O [-]	0.0025	0.0025
N in biomass [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Fraction to endogenous residue [-]	0.0800	0.0800
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200

NOB

Name	Default	Value
Yield [mgCOD/mgN]	0.0900	0.0900
N in biomass [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Fraction to endogenous residue [-]	0.0800	0.0800
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200

AAO

Name	Default	Value
Yield [mgCOD/mgN]	0.1140	0.1140
Nitrate production [mgN/mgBiomassCOD]	2.2800	2.2800
N in biomass [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Fraction to endogenous residue [-]	0.0800	0.0800
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200

OHO

Name	Default	Value
Yield (aerobic) [-]	0.6660	0.6660
Yield (fermentation, low H2) [-]	0.1000	0.1000
Yield (fermentation, high H2) [-]	0.1000	0.1000
H2 yield (fermentation low H2) [-]	0.3500	0.3500
H2 yield (fermentation high H2) [-]	0	0
Propionate yield (fermentation, low H2) [-]	0	0
Propionate yield (fermentation, high H2) [-]	0.7000	0.7000
CO2 yield (fermentation, low H2) [-]	0.7000	0.7000
CO2 yield (fermentation, high H2) [-]	0	0
N in biomass [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Endogenous fraction - aerobic [-]	0.0800	0.0800
Endogenous fraction - anoxic [-]	0.1030	0.1030
Endogenous fraction - anaerobic [-]	0.1840	0.1840
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200
Yield (anoxic) [-]	0.5400	0.5400
Yield propionic (aerobic) [-]	0.6400	0.6400
Yield propionic (anoxic) [-]	0.4600	0.4600
Yield acetic (aerobic) [-]	0.6000	0.6000
Yield acetic (anoxic) [-]	0.4300	0.4300
Yield methanol (aerobic) [-]	0.5000	0.5000
Adsorp. max. [-]	1.0000	1.0000
Max fraction to N2O at high FNA over nitrate [-]	0.0500	0.0500
Max fraction to N2O at high FNA over nitrite [-]	0.1000	0.1000

Methylotrophs

Name	Default	Value
Yield (anoxic) [-]	0.4000	0.4000
N in biomass [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Fraction to endogenous residue [-]	0.0800	0.0800
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200
Max fraction to N2O at high FNA over nitrate [-]	0.1000	0.1000
Max fraction to N2O at high FNA over nitrite [-]	0.1500	0.1500

PAO

Name	Default	Value
Yield (aerobic) [-]	0.6390	0.6390
Yield (anoxic) [-]	0.5200	0.5200
Aerobic P/PHA uptake [mgP/mgCOD]	0.9300	0.8500
Anoxic P/PHA uptake [mgP/mgCOD]	0.3500	0.2500
Yield of PHA on sequestration [-]	0.8890	0.8890
N in biomass [mgN/mgCOD]	0.0700	0.0700
N in sol. inert [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Fraction to endogenous part. [-]	0.2500	0.2500
Inert fraction of endogenous sol. [-]	0.2000	0.2000
P/Ac release ratio [mgP/mgCOD]	0.5100	0.5100
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200
Yield of low PP [-]	0.9400	0.9400
Mg to P mole ratio in polyphosphate [mmolMg/mmolP]	0.3000	0.3000
Cation to P mole ratio in polyphosphate [meq/mmolP]	0.1500	0.1500
Ca to P mole ratio in polyphosphate [mmolCa/mmolP]	0.0500	0.0500
Cation to P mole ratio in organic phosphate [meq/mmolP]	0.0100	0.0100

Acetogens

Name	Default	Value
Yield [-]	0.1000	0.1000
H2 yield [-]	0.4000	0.4000
CO2 yield [-]	1.0000	1.0000
N in biomass [mgN/mgCOD]	0.0700	0.0700
P in biomass [mgP/mgCOD]	0.0220	0.0220
Fraction to endogenous residue [-]	0.0800	0.0800
COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200

Methanogens

Name	Default	Value
Acetoclastic yield [-]	0.1000	0.1000
Methanol acetoclastic yield [-]	0.1000	0.1000
H2-utilizing yield [-]	0.1000	0.1000
Methanol H2-utilizing yield [-]	0.1000	0.1000
N in acetoclastic biomass [mgN/mgCOD]	0.0700	0.0700
N in H2-utilizing biomass [mgN/mgCOD]	0.0700	0.0700
P in acetoclastic biomass [mgP/mgCOD]	0.0220	0.0220
P in H2-utilizing biomass [mgP/mgCOD]	0.0220	0.0220
Acetoclastic fraction to endog. residue [-]	0.0800	0.0800
H2-utilizing fraction to endog. residue [-]	0.0800	0.0800
Acetoclastic COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200
H2-utilizing COD:VSS ratio [mgCOD/mgVSS]	1.4200	1.4200

Appendix B

PROCESS OPTIMIZATION TESTING AND SAMPLING PLANS

TESTING PLAN

Treatment Performance without Filtrate Recycle

To:	Santa Fe Plant Staff
Copies To:	Becky Luna, Bryan Coday
From:	Tanja Rauch-Williams
Date:	August 22, 2017
Project:	Nutrient Loading and Removal Optimization Study
Subject:	Testing Plan: Simulation of treatment performance without filtrate recycle impacts on main stream treatment

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This plan summarizes the proposed testing protocol for the Alternative "Simulation of treatment performance without filtrate recycle impacts" under Task 4 in Phase 2 - Support full-scale optimization verification tests.

This alternative was selected by treatment staff as one of four strategies to be full-scale tested as discussed at the Workshop 2 (Process Capacity and Optimization) to better understand the feasible effluent goals for nutrients that the Paseo Real WWTP may be able to achieve after process optimization.

1.0 TESTING OBJECTIVE

The objective of the full-scale testing of this alternative is to assess the improvements in effluent quality that can be achieved through management of the nutrient recycle loads from filtrate recycling through side stream treatment. Filtrate from belt filter press dewatering at the Paseo Real WWTP contains high phosphorus and nitrogen loads that impact the biological nutrient removal (BNR) performance of the main stream treatment train.

Based on the current sampling set-up, the plant influent samples collected by plant staff include the filtrate recycle stream. Therefore, long-term historical data separately characterizing the filtrate recycle and the plant influent flows is not available. Process modeling could not be calibrated to differentiate between both process streams. Therefore, Carollo Engineers, Inc. (Carollo) was unable to use the model to theoretically assess the impact of recycle flows on main stream BNR treatment. It is anticipated that nutrient recycle loads may have a significant impact on effluent quality. As such, side stream treatment of the filtrate for phosphorus and / or nitrogen removal may be a cost-effective strategy for the Paseo Real WWTP to further reduce effluent nutrient concentrations.

The specific goals of the testing are as follows:

1. Quantify the improvement in secondary and final plant effluent nitrogen and phosphorus concentration without filtrate recycling to the main stream.

   a. Simulate main stream treatment operation and performance full-scale under simulated side stream treatment of filtrate for nitrogen and phosphorus removal.

2. Identify any other potential plant-wide consequences (negative or positive) of operating the main stream treatment without filtrate recycle loads.

2.0 TESTING CONDITIONS

The Paseo Real WWTP continuously operates two belt filter presses and recycles filtrate directly back to the headworks without intermediate storage. The plant has two primary clarifiers of which only one unit is typically in operation. Plant staff has the flexibility to store filtrate temporarily in the off-line primary clarifier. This option is preferred compared to the alternative to store sludge prior to dewatering. In order to route filtrate to the off-line primary clarifier, temporary bypass pumping will need to be put into place. Plant staff will access the manhole on the northeast of the Industrial Pretreatment and Engineering Building to install a plug in the downstream piping to the headworks. A pump will be placed into this manhole, and temporary overland piping will be used to route filtrate from the manhole to the primary clarifier. The plug, pump, and bypass piping are available onsite.

Table 1 summarizes the design criteria and anticipated storage time in the primary clarifier.

Table 1: Design Criteria of the Primary Clarifiers and Filtrate Production Rates

Parameter	Units	Value
Primary Clarifiers		
Number of Units	-	2
Volume, each	gal	580,600
Filtrate Storage		
Filtrate Flows	gpd	58,400$^{(1)}$
Estimated Storage Time (1 clarifier)	days	9.9
1. Average of the filtrate flows recording during special testing between May 9-20, 2017.		

Table 2 summarizes the Total Kjeldahl Nitrogen (TKN) and total phosphorus (TP) concentrations in filtrate based on data collected during May 9-20, 2017 and the estimated loads compared to the influent flow. Recorded filtrate concentrations are highly variable, making it difficult to estimate the contribution of filtrate loads on the plant influent. First estimates for TP and TKN load contributions documented in Table 2 are relatively low compared to other BNR facilities where TP and TKN recycle loads contribute typically between 15 and 30 percent of the plant influent load. This test will help to verify these estimates and reveal the extent to which side stream treatment can improve effluent quality.

Table 2: Filtrate and Plant Influent

Parameter	Units	TP	TKN
Filtrate			
Average Flow	mgd	0.0584	
	gpd	40.5	
Concentration(1)	mg/L	173	462
Load	ppd	84	27
Plant Influent (includes filtrate)			
Average Flow	mgd	5.5	
Concentration	mg/L	14	80
Load	ppd	642	440
Filtrate Load as % of Influent		**>15%**	**>7%**

1. Average of the filtrate flows recording during special testing between May 9-20, 2017.

3.0 TESTING APPROACH

During this test, plant staff will redirect all filtrate recycle flows from the dewatering complex to the off-line primary clarifier for intermittent storage. During this period the mainstream secondary treatment and plant effluent quality will be closely monitored to assess treatment changes compared to the typical operation when filtrate is directly recycled to the plant headworks.

Operations staff will check on the pump operation every 2 hours during their regular walkthroughs. Should the pump operation fail and go unnoticed during continuous sludge dewatering, filtrate is anticipated to overflow the manhole next to the dewatering facility. Odors are not anticipated to be a concern per discussions with operations staff.

It is anticipated that some settling will occur during filtrate storage in the primary clarifiers. Plant staff can assess settling during the testing and activate the primary sludge pumps as needed to transfer filtrate back to the digesters. A sludge blanket reader will be used to determine whether the primary sludge pumps need to be operated intermittently. If necessary, filtrate could also be pumped to the drying beds, and from there back to the RAS wetwell. However, it is not anticipated that this will become necessary during the testing.

The testing of this alternative will start with two weeks of baseline operation and treatment monitoring. Each of the following three operational test phases is scheduled to last about 7 to 9 days (Table 3) with operational changes being made Monday mornings.

Table 3: Testing Plan Overview

Test Phase	Filtrate Operation	Objective	Dates
Baseline Start	As typical, filtrate routed to headworks without storage	Collect baseline process data for comparison with Test Phase 1	8/28/2017-9/11/2017 (2 weeks)
Test Phase 1	Route filtrate to PC for storage	Simulation of treatment performance without filtrate nutrient loads	9/11/2017-9/18/2017 (about 7 days)
Drainage Phase	Drain filtrate slowly from primary clarifiers back to the aeration basins	Empty off-line primary clarifier while load spikes in the aeration basins	About 1-2 weeks
Baseline 2 (optional)	As typical, filtrate routed to headworks without storage	Repeat testing if necessary for statistically significant results	TBD
Test Phase 2 (Optional)	Route filtrate to PC for storage		TBD
Notes: 1)			

During this testing, any necessary changes to plant operation that may affect testing, secondary treatment performance, or filtrate quality and flows should be documented and (ideally) made in small increments.

4.0 DATA COLLECTION

The sampling plan to accompany this testing is summarized in the attached Excel file.

5.0 TEST EVALUATION

Test data will be summarized and organized by plant staff and shared with Carollo towards the end of each testing period. A brief phone consultation will be held between plant staff and Carollo prior to moving on to the next testing period. Towards the end of the testing period, Carollo will provide support with the statistical data evaluation, preparation of graphs and figures, and interpretation of the overall test results.

		BASELINE START														TEST PHASE 1						
	Date	28-Aug	29-Aug	30-Aug	31-Aug	1-Sep	2-Sep	3-Sep	4-Sep	5-Sep	6-Sep	7-Sep	8-Sep	9-Sep	10-Sep	11-Sep	12-Sep	13-Sep	14-Sep	15-Sep	16-Sep	17-Sep
		Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Mon - Labor day**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**
	Samling Parameter																					
INF	Flow (MGD)	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
	TSS	x		x	x					x	x	x			x		x	x	x	x	x	
	~~VSS~~	~~x~~		~~x~~	~~x~~					~~x~~	~~x~~	~~x~~			~~x~~		~~x~~	~~x~~	~~x~~	~~x~~	~~x~~	
	BOD$_5$																					
	CBOD5																					
	COD	x		x	x					x	x	x			x		x	x	x	x	x	
	Ammonia	x		x	x					x	x	x			x		x	x	x	x	x	
	TKN	x		x	x					x	x	x			x		x	x	x	x	x	
	sTKN																					
	TP	x		x	x					x	x	x			x		x	x	x	x	x	
	O-PO4	x		x	x					x	x	x			x		x	x	x	x	x	
FILT	Belt Press 1 (gpd dewatered)	x	x	x	x	x	x	x	x	x	x	x	x		x							
	Belt Press 2 (gpd dewatered)	x	x	x	x	x	x	x	x	x	x	x	x		x							
	TKN	x		x	x					x	x	x			x							
	TP	x		x	x					x	x	x			x							
	Alkalinity	x																				
	COD	x		x	x					x	x	x			x							
	TSS	x		x	x					x	x	x			x							
	VSS																					
SE	Flow (MGD)																					
	TSS	x		x	x					x	x	x			x			x		x	x	
	VSS																					
	BOD$_5$																					
	CBOD5																					
	COD	x		x	x					x	x	x			x			x		x	x	
	Ammonia	x		x	x					x	x	x			x			x		x	x	
	TKN																					
	sTKN																					
	TP	x		x	x					x	x	x			x			x		x	x	
	O-PO4																					
FE	Flow (MGD)	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
	TSS	x		x	x				x	x	x	x	x		x		x	x	x	x	x	
	VSS																					
	BOD$_5$																					
	CBOD5																					
	COD	x		x	x				x	x	x	x	x		x		x	x	x	x	x	
	Ammonia	x		x	x				x	x	x	x	x		x		x	x	x	x	x	
	TKN	x		x	x				x	x	x	x	x		x		x	x	x	x	x	
	~~sTKN~~	~~x~~		~~x~~	~~x~~				~~x~~	~~x~~	~~x~~	~~x~~	~~x~~		~~x~~		~~x~~	~~x~~	~~x~~	~~x~~	~~x~~	
	TP	x		x	x				x	x	x	x	x		x		x	x	x	x	x	
	O-PO4	x		x	x				x	x	x	x	x		x		x	x	x	x	x	

TESTING PLAN

Alternative Aeration Patterns to Reduce Effluent Nitrogen

To:	Santa Fe Plant Staff
Copies To:	Becky Luna
From:	Tanja Rauch-Williams
Date:	November 20, 2017
Project:	Nutrient Loading and Removal Optimization Study
Subject:	Testing Plan: Alternative Aeration Patterns to Reduce Effluent Nitrogen

This plan summarizes the proposed testing protocol for the Alternative "Alternative Aeration Patterns to Reduce Effluent Nitrogen" under Task 4 in Phase 2 - Support full-scale optimization verification tests.

This alternative was selected by treatment staff as one of four strategies to be full-scale tested as discussed at the Workshop 2 (Process Capacity and Optimization) to better understand the feasible effluent goals for nutrients that the Paseo Real WWTP may be able to achieve after process optimization.

1.0 TESTING OBJECTIVE

The objective of the full-scale testing of this alternative is to assess the improvements in effluent quality that can be achieved through management of the aeration pattern along the aeration basin trains and throughout the day.

The specific goals of the testing are as follows:

1. Assess the necessary oxygen profile throughout the aeration basins for completely removing ammonia while keeping the DO profile as low as possible to maximize the removal of nitrogen in the secondary treatment.
2. Identify the most beneficial DO pattern along the length of the aeration basins and during the day under possible inclusion of all diffuser grids to maximize the amount of simultaneous nitrification and denitrification (SNDN).
3. Adjust the mixed liquor recycle flow to the anoxic selectors for optimal nitrate and phosphorus removal once SNDN has been optimized.
4. Assess any other potential plant-wide consequences (negative or positive) of operating the main stream treatment without filtrate recycle loads.

2.0 TESTING CONDITIONS

The Paseo Real WWTP has two oxidation ditch-style aeration basins in service that are equipped with diffuser grids in Passes A, B, and C. Pass D cannot be aerated. The facility typically aerates Passes A and B and does not operated diffusers in Passes C. In Summer 2017, each aeration basin was equipped with two relocatable DO probes. In addition the South Train was equipped with an online Ammonia analyzer in the basin effluent, and an online nitrate probe in the D Pass.

Table 1 summarizes all available online probes and the recommended initial locations in the North and South Trains.

Table 1: List of Online Sensors and Initial Recommended Locations in the Process During This Testing

Probe	Process Location
Shimatzu Analyzer (TOC, TP, TN)	Final Effluent
Nitrate Probe	Anoxic Selector, last basin, towards effluent weir
Oxygen Probe LDO4ND026	North C Pass
Oxygen Probe LDO3NC021	North B Pass
Oxygen Probe LDO1SA029	South B Pass
Oxygen Probe LDO2SC023	South C Pass
Nitrate Probe NIT1SD319	South D Pass
Ammonia Analyzer AMSC282	South train - towards the basin effluent

Table 2 summarizes the recommended facility configuration and operational setpoints during testing. Operations staff should attempt to keep these conditions as stable as possible during the testing, document any required deviations, and immediately inform supervisory staff and Carollo Engineers of their reasons.

Table 2: Facility Configuration and Operational Target Setpoints During Testing

Operation Variable	**Control Point**	**Change?**	**Action**
Primary Clarifiers in Operation	Plant inf flow to Clarifier No. 1 and/or No. 2	No	All Plant Influent **diverted** to No. 2 **(1 out of service)**
Primary Clarifier Blankets	Primary sludge pumping rate to digester(s)	No	**Maintain** sludge blanket thickness between **5 and 7 ft**
Selector Basins in Operation	Primary eff to Basins A and/or B, C and D in operation as well	No	All Selectors **in operation** (w/ mixers **on**), Aeration to Selectors A/B is **OFF**
Selector Basins C/D Aeration	Aeration air to Basins C and/or D	No	Aeration to Selectors C/D is **OFF**
Aeration Basins in Operation	Selector Basin eff flow to North and/or South ABs	No	North/South ABs **in operation** with same air distribution (w/ mixers **on**)
Aeration Grids in Operation	Grids On/Off (same for both ABs)	See Table 3 for details	See Table 3 for details
Dissolved Oxygen in ABs	Air flow to grids in each AB pass	See Table 3 for details	See Table 3 for details
MLSS Recycle Flow	MLSS Pumps On/Off (each pump supplies approx. 3400 gpm)	No	Single pump **ON** (rotated as needed) (Day and Graves)
Secondary Clarifiers in Operation	AB eff to various clarifiers	No	Turn **OFF** flow to Clarifiers 5 & 6 (“new”) as flow decreases on graveyard shift. Turn **OFF** flow to Clarifier 4 if needed to maintain water level in remaining (vacuum) clarifiers
Secondary Clarifier Blankets	Recycle Activated Sludge (RAS) pumping rate	No	**Maintain** sludge blanket thickness between **5 and 7 ft**
Mean Cell Residence Time (MCRT – Sludge Age)	Waste Activated Sludge (WAS) pumping rate	No	Adjust WAS to **maintain** MCRT between as close as possible to 12 days (11-13 days), as calculated in Ops10 (assumes North and South ABs **ON**). Calculate and record MCRT daily including on weekends.
Disk Filter Operation	Filters On/Off	No	Maintain 2 filters **ON** at all times (filter 2 is down for maintenance)
Sand Filter Operation	Filters On/Off	No	Filters 4 and 5 are **OFF** (inoperable)
UV Disinfection Operation	Channel Flow	No	Channel 2 is **OFF** for maintenance
UV Disinfection Operation	Banks and Lamps	No	Maintain 3 Channels **ON** at all times Maintain all Banks/Lamps **ON** at all times
Post Aeration	Post Aeration Basin air flow	N	Adjust airflow to **maintain** eff DO above 5.0 mg/L)
Effluent Discharge	Reclaimed Wastewater Flow to Users	(na)	Adjust to maintain minimum flow eff flow to Santa Fe River

3.0 TESTING APPROACH

The test plan is set up in multiple test phases outlined in Table 3. It is critical that the process configuration remains constant and all operational setpoints remain as stable as possible in order to allow assessing the effect of one variable - DO profile in the aeration basins (independent variable) - on the testing result of interest - effluent total nitrogen (dependent variable). If deviations must be made for relevant reasons (e.g. to assure continued permit compliance, etc.), please document the changes and inform supervisory staff and Carollo Engineers on the same day (Tanja Rauch-Williams, trauch-williams@carollo.com, 720-670-0479).

Maintain DO in each Pass as indicated in Table 3 where either grid is **ON** as close as possible to the specified setpoints by adjusting the airflows to the respective grids throughout the day. Operating at low stable DO concentrations allows for the bacteria community in the activated sludge to adapt over time and maximize SNDN performance. The adaptation time depends on several factors, including temperature, consistent environmental conditions (i.e. DO), and solids retention time. It is therefore very important to keep the MCRT stable. Adjustments to the TSS wasting loads and MLSS concentration in the ditches should be made accordingly and in slow incremental changes.

Since the facility does not have the ability to monitor ammonia and nitrate concentrations in the North and South Train independently online, it is recommended to operate aeration (grid operation and DO target setpoints) to both trains in exactly the same manner. Conducting the testing during winter and low temperature conditions improves

Table 3: Testing Plan Overview, Aeration Basin Grid Operation, and Target DO Setpoints

Test Phase	Objective	Aeration Grids in Operation and DO Setpoints for North and South Train	Dates / Duration
Baseline Phase	Collect baseline process data for comparison with subsequent test phases.	Pass A – Both grids **ON - DO 1.0-1.5 mg/L** Pass B – First grid **OFF**, second grid **ON DO 0.5 to 1.0 mg/L** Pass C – Both grids **ON - DO Setpoint 0.3 mg/L**	3-4 weeks (2-3 MCRT cycles) Start: 11/27/2017
Test Phase 1	Simulation of treatment performance with modified Aeration Pattern	TBD. Will be modified based on results of "Baseline Phase"	Dec 17/Jan 18 (2-3 MCRT cycles)
Test Phase 2	Repeat testing if necessary for statistically significant results	TBD. Will be modified based on results of the first two test phases	Jan - Feb 18 (2-3 MCRT cycles)
Notes: 1)			

4.0 COORDINATION AND COMMUNICATION

The testing is proposed to start the Monday after Thanksgiving week in 2017. Each test Phase is recommended to be maintained for about 2 to 3 MCRT cycles (20-30 days) to allow for the bacteria to adapt to the DO conditions (Table 3) with operational changes being made Tuesday mornings.

Weekly, brief conference calls will be scheduled between plant staff and Carollo Engineers to make small adjustments to the DO setpoints based on the observed effluent quality as necessary. These calls will be held on Mondays.

Plant staff is asked to upload to the project sharepoint site the following data Fridays or Monday mornings each week before the calls so data can be reviewed:

- Online sensor data from all devices listed in Table 1
- MCRT data (as calculated by the plant staff) and MLSS concentrations
- Effluent quality (all nutrients, TSS, organics) as measured by the facility lab.

5.0 DATA COLLECTION

Operations staff will check on the DO readings every 2 hours during their regular walkthroughs and make adjustments as necessary to maintain stable DO conditions.

MCRT will be calculated and tracked on a daily basis including weekends.

Staff is encouraged to review online data on a daily basis to assure that DO profiles throughout the day remain close to target conditions in all Passes with probe devices. Since Passes A do not have online DO probes, it is recommended to use a handheld DO probe and record DO readings throughout the day to assure stable DO operation.

At this time, no special sampling is requested from the lab. Depending on the testing results, it may be beneficial to conduct ammonia, nitrate, and ortho-P profile testing throughout the selectors and aeration basins. This will be discussed in the weekly update calls as necessary.

6.0 TEST EVALUATION

Test data will be summarized and organized by plant staff and shared with Carollo towards the end of each testing period. Towards the end of the testing period, Carollo will provide support with the statistical data evaluation, preparation of graphs and figures, and interpretation of the overall test results. These results will be included in the Draft and Final Project Technical Memorandum.

Appendix C

PROJECT MEMORANDUM – RECOMMENDATIONS FOR ONLINE SENSOR PROCUREMENT

PROJECT MEMORANDUM - FINAL

NUTRIENT LOADING AND REMOVAL OPTIMIZATION STUDY

Date:	5/11/2017
Project No.:	10515A00

City of Santa Fe

Prepared By:	Tanja Rauch-Williams, PhD, PE, and Bryan Coday, PhD
Reviewed By:	Becky Luna, PE
Subject:	Recommendation for Online Sensor Procurement for Process Optimization

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Introduction

This Project Memorandum (PM) provides an overview of the online sensors recommended for process monitoring and optimization at the Paseo Real Wastewater Treatment Plant (WWTP). This summary was written to support the City of Santa Fe's (City) Nutrient Loading and Removal Optimization Study. The recommended online instrumentation is separated into near-term sensors (to be procured immediately) and sensors to be procured in a second purchasing phase that could be initiated as soon as summer 2017.

A detailed discussion of advantages and limitations of different sensor options, possible process monitoring locations, vendor alternatives, and maintenance implications was conducted with the City in the Project Kick-off Workshop (held at the Paseo Real WWTP on March 17, 2017) and in a subsequent conference call between Carollo Engineers (Carollo) and City staff.

Criteria for Sensor Selection

Several factors were considered when selecting the online instrumentation for process control and optimization at the WWTP as listed below:

- Analytical methods used by the sensor,
- Concentration ranges and instrument sensitivity and limit of quantification,
- Reliability and drift,
- Initial capital and long-term operational costs (e.g., replacement parts and reagent costs),
- Frequency and time requirement for calibration and maintenance,
- Experience of other reference facilities,
- Value of information recorded for operational decisions and risk mitigation, and
- Anticipated quality of regional vendor support.

The following process parameters were identified as possible candidates for online monitoring:

- Dissolved oxygen (DO),
- pH,
- Nitrate and nitrite,
- Ammonium,
- Ortho-phosphorus (OP),
- Biochemical oxygen demand (BOD) or chemical oxygen demand (COD),

- Oxidation-reduction potential (ORP),
- Total suspended solids (TSS), and
- Sludge blanket depth.

There are a variety of analytical methods and commercially available probes or analyzers that can measure each of these parameters in different process stream matrices. Product overviews, including a synopsis of available analytical methods, vendors, operation and maintenance (O&M) requirements, and network components were summarized in the kick-off meeting and can be referenced in the PowerPoint presentation and meeting minutes.

Recommended Sensor Selection and Process Location

The recommended probes and process locations are summarized in Table 1 along with a justification of how the real-time data can educate operational decisions. Aerial photographs showing recommended probe and transmitter locations in the aeration basins and anoxic selectors are provided in Appendix A.

Table 1 Recommended Probes for Near- and Long-term Procurement by the Paseo Real WWTP

Probe Type	Number of Probes	Locations	Justification
Current Acquisition (already ongoing)			
Total Nitrogen and Total Phosphorous Analyzer (Shimatzu Model TNPC-4110C)	1 Analyzer	• Final plant effluent	• Diurnal effluent quality monitoring or permit compliance
Near-term (Immediate) Procurement - Phase 1			
Anoxic Selectors			
Nitrate	1	• One of the two second stage anoxic selectors towards the outlet • Relocatable between both selector trains	• Monitoring of nitrate at end of anoxic zone to optimize mixed liquor return flows
ORP	1	• Near-term: a hand held unit to periodically assess ORP profile in selector zones and aeration basins • If this parameter is useful for plant staff, install one or several permanent probes in the process	• Further testing is necessary to demonstrate value of probe for plant operation • Additional information for identifying best site-specific conditions is necessary
DO	4	• 2 per aeration basin train • Transmitter located on north-south bridge across basins • Probe 1 located in Pass B, Probe 2 relocatable between Passes C or D if necessary	• Optimization of nitrogen removal in the aeration basins through simultaneous nitrification/ denitrification • Optimization of energy input through aeration • Diurnal process optimization • Basis for possible future aeration automation • Alleviates manual DO monitoring by plant staff

Table 1 Recommended Probes for Near- and Long-term Procurement by the Paseo Real WWTP (con't.)

Probe Type	Number of Probes	Locations	Justification
Aeration Basins			
Nitrate	1	• South Aeration Basin • Close to basin effluent location, e.g. relocatable between Passes C or D	• Optimization of nitrogen removal in the aeration basins through simultaneous nitrification/ denitrification • Diurnal process optimization • Basis for possible future aeration automation
Ammonium (It is recommended to test this probe first prior to purchase)	1	• South Aeration Basin • Needs to be placed where ammonium is consistently around or above 2 to 3 milligrams per liter (mg/L) after process optimization • Exact location to be determined through profile testing • Relocatable between Passes B, C, or D	• Real-time monitoring and optimization of both the aeration rate and simultaneous nitrification-denitrification performance in the aeration basins • Diurnal process optimization • Basis for possible future aeration automation
Preliminary Phase 2 Procurement Recommendations			
Nitrate	1	North Aeration Basin Train	Equip the second aeration basin train with same instrumentation as the South Train
Ammonium	1	North Aeration Basin Train	Equip the second aeration basin train with same instrumentation as the South Train
OP Analyzer	1	In mixed liquor process	May help optimize biological phosphorus removal
TSS	2	1 per aeration basin train	TSS probes in the aeration basins help with overall inventory management and tighter solids retention time (SRT) control
ORP	1	Anaerobic selectors	Equip the second selector train with same instrumentation
Sludge Blanket	TBD	Primary clarifiers or secondary clarifiers	Sludge blanket probes can be used to optimize fermentation in the primary clarifiers and RAS recycle in the secondary clarifiers

As shown in Table 1, Carollo recommends separating the procurement of the sensors into at least two phases. Probes immediately needed for process monitoring, optimization, and calibration of a plant-wide process model were prioritized for immediate purchase. It is recommended that plant staff adopts these probes first and becomes familiar with their operation, maintenance, and calibration needs. After this, additional probes or analyzers can be phased in to monitor the second process train and help the WWTP maintain consistent seasonal and diurnal biological nutrient removal (BNR) performance. Phase 2 procurement recommendations can be re-evaluated after the Phase 1 probes have been in service for a few months.

Vendor Selection

Several probe manufacturers were considered in this evaluation, including YSI, Endress & Hauser, Hach, and S::can. At the direction of the City, Hach was solicited for cost estimates and a detailed scope of supply for the Phase 1 acquisition. This vendor has a large local presence (more than 50 accounts in New Mexico) and a history of reliable probe performance at other regional WWTPs. A local subcontractor will be hired by the City to evaluate the electrical connections and routing of power and data conduits to the proposed transmitter locations.

Hach Cost Proposal

The cost proposal solicited from Hach considered the following:

- The specific probe models recommended for Phase 1 implementation, as listed in Table 1,
- Two transmitters for placement on the bridge of the aeration basins and the anoxic selectors (with and without mobile access option), respectively, and
- Service contract fees versus chemical and replacement part costs for maintenance and operation (these O&M costs would otherwise be included in the service contract fee).

Tables 2 and 3 summarize the model numbers for probes and transmitters and lists alternative price options, where available, for further discussion with the City. Specification sheets for each piece of equipment are included in Appendix B. The listed costs are based on Hach's final cost proposal accepted by the City.

Table 2 Hach Model Numbers and Estimated Costs for Phase 1 Equipment

Parameter	Hach Part	Additional Hach Components	Quantity	Unit Cost, $	Total Price
DO	LDO Model 2 Probe		4	$1,763.64	$7,054.56
	KTP Pole Mount, Sensor		4	$443.44	$1,773.76
	Mylar Bag, Calibration		1	$5.11	$5.11
	50-foot extension cable		2	$249.32	$498.64
	100-foot extension cable		2	$331.20	$662.40
	Consumables: Caps on end of DO probes, replaced every 2 years (about $150)				
				TOTAL	**$9,995**
Nitrate	NITRATAX Plus sc, immersion self-cleaning, with data logger	path length: 2 mm	2	$16,159.80	$32,319.60
	Pole Mounting Hardware		2	$510.60	$1,021.20
	Control Standard, 25 mg/L NO_3		1	$55.06	$55.06
	50-foot extension cable		1	$249.32	$249.32
	100-foot extension cable		3	$331.20	$993.60
	Wiper replacement about every 6 months (very low costs) Seal exchange done by trained rep send in for 7 days annually is $750 per seal), or covered by service contract)				
				TOTAL	**$34,639**
Ammonium(1)	AISE sc ISE Probe 10-foot cable (will need to be longer)	quantification limit 0.1 mg/L	1	$7,428	$7,428
	Sensor Cartridge Replacement Consumable with Shipping Boot (every 6 months) / without service agreement		1	$989	$989
	Cleaning Unit (valuable for low ammonium concentrations) - purchase could be postponed until after trial		1	$289	$289
	Clean System, High Output Air Blast Hach 115V (valuable for low ammonium concentrations) - purchase could be postponed until after trial		1	$1,927	$1,927
				TOTAL	**$10,633**

Table 2 Hach Model Numbers and Estimated Costs for Phase 1 Equipment (con't.)

Parameter	Hach Part	Additional Hach Components	Quantity	Unit Cost, $	Total Price
ALT 1: Process Differential ORP (Permanent Installation)	pHD sc, ORP Sensor,	PEEK Body, Convertible body style, Platinum	1	$1,086	$1,086
	Mounting Hardware		1	$468	$468
	Standard cell solution (lasts for 2 years)		1	$70.19	$70.19
	Salt Bridge (replace every 6 months, refill with standard solution)		1	$78.19	$78.19
	ORP Reference Solution (solution for calibrating every 2 months)		1	$61.55	$61.55
	25-foot Extension Cable		1	$182	$182
				TOTAL	**$1,946**
ALT 2: Grab Sample ORP (Lab Instrument)	ORP Gel filled Tube with 15-foot cable		1	$554.76	$554.76
	ORP Standard Solution		1	$48.90	$48.90
	Storage Solution		1	$32.25	$32.25
				TOTAL	**$636**

Notes:

(1) Hach has an AISE sc ISE ammonium probe available that is currently being used for a 1-month (or longer) demo at the WWTP.

Table 3 Hach Scope of Supply and Estimated Cost for Transmitters

Hach Transmitter	Hach Part	Quantity	Unit Cost, $	Total Price
ALT 1: SC1000 Controller (Integrates with Communication Systems)	6 Sensor Input, 2x4-20 MA Ouput(1)	2	$2,880.52	$5,761.04
	Module, Display, SC 1000	2	$3,284.40	$6,568.80
	Sunshield (City will provide additional transmitter protection in-house, as deemed necessary by plant staff)	2	$149.96	$299.92
			TOTAL	**$12,630**
ALT 2: SC1500 Controller (Does not have a local monitor at this time, needs phone or tabloid to see data. - SCADA integration possible in future - only analogue output at this time. Not yet integrated with communication systems)	6 Sensor Input, 8mA Output(1)	2	$2,978	$5,956
	Modem Kit	2	$490	$980
	Service startup Fee	1	$500	$500
	SIM Card (work with AT&T, etc.), not yet included	1		
	Annual Service Fee (sensor connection to the Cloud and data delivery		$264	$1,056
	Annual Subscription for Nitratax Sensors	2	$264	$528
			TOTAL	**$9,020**

Notes:

(1) The SC1000 transmitter includes provisions for local data logging and downloads via an SD card. These transmitters can be upgraded to SC1500 units, which enable remote communication and data downloads via a cloud based data management system. Allows up to 6 probe port connections.

Table 4 Hach Field Service

Instrument	Service Scope	Total Cost
AISE Ammonium Probe (1)	Instrument start-up, all parts, labor, and travel for on-site repairs, 2 on-site calibrations per year, factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates	$3,103
DO Probes (4)		$1,888
Nitratax (2)		$2,156
Process OPR (1)		$237
SC 1000 Controller (2)		$500
	TOTAL	**$7,884**

Table 5 Summary of Costs for Phase 1 Instrumentation Procurement Options

Item	Alternative 1	Alternative 2
All Probes and Sensors (DO, Nitrate, Ammonium)	$55,267	$55,267
ORP (Process Probe-ALT1; Lab Probe - ALT2)	$1,946	$636
Controllers (SC1000 - ALT 1; SC1500 - ALT2)	$12,630	$9,020
Service Contract (1 year)	$7,884	$7,884
TOTAL	**$77,727**	**$72,807**
Shipping and Handling (>$10,000, 2%)	**$1,555**	**$1,456**
Sales Taxes (if shipped from Loveland, CO) (5.125%)	**$3,984**	**$3,732**
GRAND TOTAL	**$83,266**	**$77,995**

Final Recommended Procurement List and Costs

Table 6 presents the final selected procurement list and costs for the Phase 1 purchase contract. The detailed cost estimate from Hach can be reviewed in Appendix D of this PM. In order to not exceed the $60,000 instrumentation budget for this project, the Hach service contracts were removed from Carollo's purchasing agreement and will be paid separately by the City. Hach also applied an 8 percent discount to the unit price of all equipment listed in the final cost estimate to help reduce the costs. The cost for the ammonium probe and associated equipment is not included in this purchasing agreement as the probe is currently under testing at the WWTP site. Once the probe has been proven reliable to plant staff, the City will procure the equipment under a separate purchasing contract.

Table 6 Final Cost Summary for Phase 1 Instrumentation Procurement

Item	Cost
Probe and Ancillary Equipment	
DO	$9,995
Nitrate	$34,639
ORP (Lab Probe - ALT2)	$636
Controllers (SC1000 with Display Module - ALT 1)	$12,630
TOTAL EQUIPMENT COST	**$57,900**
Shipping and Handling (>$10,000, 2%)	**$1,085**
Sales Taxes (shipped from Loveland, CO) (5.125%)	**$2,967**
GRAND TOTAL	**$61,952**

At this time, the City has chosen to purchase a lab ORP probe (ALT2) to periodically assess the ORP profile in the secondary process. If plant staff decides that this parameter is useful for process monitoring and optimization, the City can purchase and install permanent ORP probes in the future. Performance data collected with the lab probe will be useful when identifying the best locations for a permanent installation.

COLORADO LICENSED PROFESSIONAL ENGINEER
BECKY J. LUNA
39920

Digitally signed by Becky J. Luna
Contact Info: Carollo Engineers, Inc.
Date: 2017.05.11 15:53:03-06'00'

Reviewed by:

Becky J. L

Becky J. Luna, PE

Appendix A

RECOMMENDED LOCATIONS OF ONLINE PROBES AND TRANSMITTERS

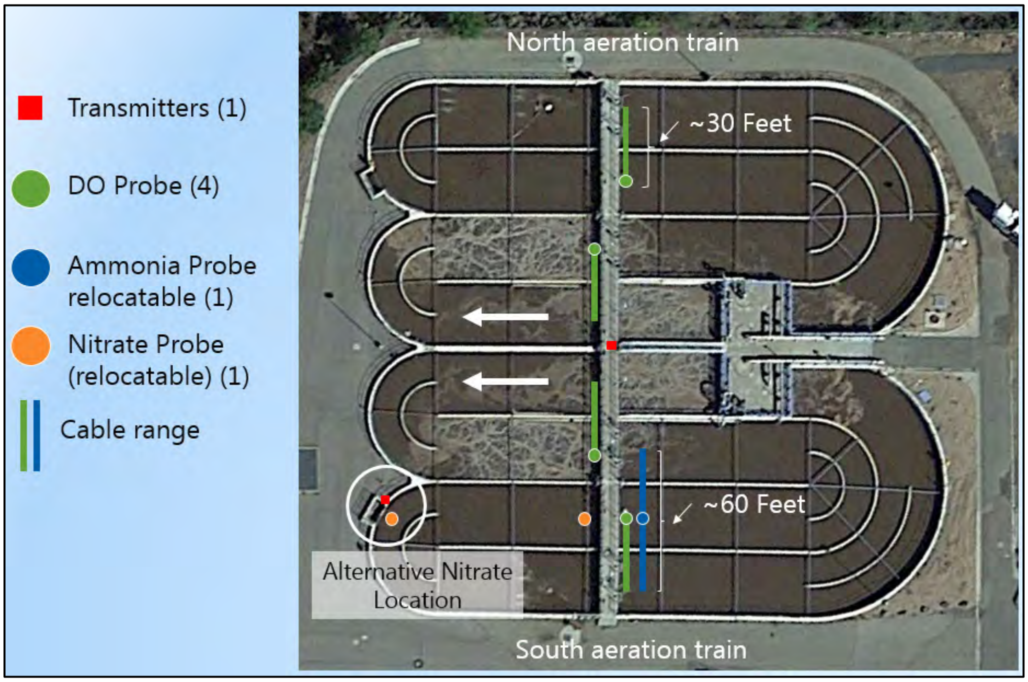


Figure 1A Proposed Near-Term Probe and Transmitter Locations in the Aeration Basin Trains

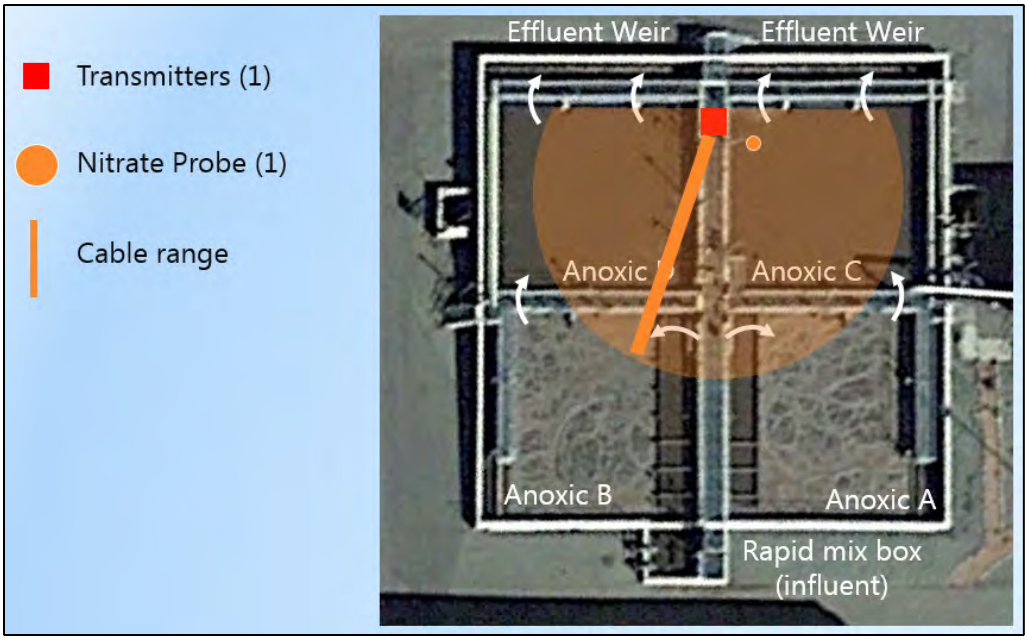


Figure 2A Proposed Near-Term Probe and Transmitter Locations in the Anoxic Selectors

Appendix B

EQUIPMENT DATA SHEETS

Dissolved Oxygen: Hach LDO® Probe, Model 2

Applications

- Wastewater
- Industrial Water
- Drinking Water

Take "No" for an answer when measuring dissolved oxygen with the next generation Hach LDO probe.

No Calibration Required

The Hach LDO probe is ready to work in your process right out of the box with no calibration required for the entire 2 year life of the sensor cap.

No Membranes to Replace

There is virtually no maintenance with Hach's breakthrough luminescent technology, as there are no membranes to replace, no electrolyte solution to replenish, and no anode or cathode to clean.

No Missed Cleaning Cycles

Customizable service indicators trigger a service message so that a cleaning cycle is never missed.

No Drift

A cutting-edge 3D calibration procedure at the factory makes oxygen measurement with the Hach LDO probe more accurate than ever before.

No Complications

A robust new design gives the Hach LDO enhanced durability and reduced size for easier handling.

HACH®

Be Right™

Specifications*

Measuring Range	0 - 20.00 ppm 0 - 20.0 mg/L 0 - 200% saturation
Accuracy	±0.1 ppm Below 5 ppm ±0.2 ppm Above 5 ppm Temperature: ±0.2°C
Response Time	at 20ºC: To 95% in less than 60 seconds To 90% in less than 40 seconds
Resolution	0.01 ppm (mg/L) / 0.1% saturation
Repeatability	±0.1 ppm (mg/L)
Operating Temperature	0 to 50°C (32 to 122°F)
Flow Rate	None required

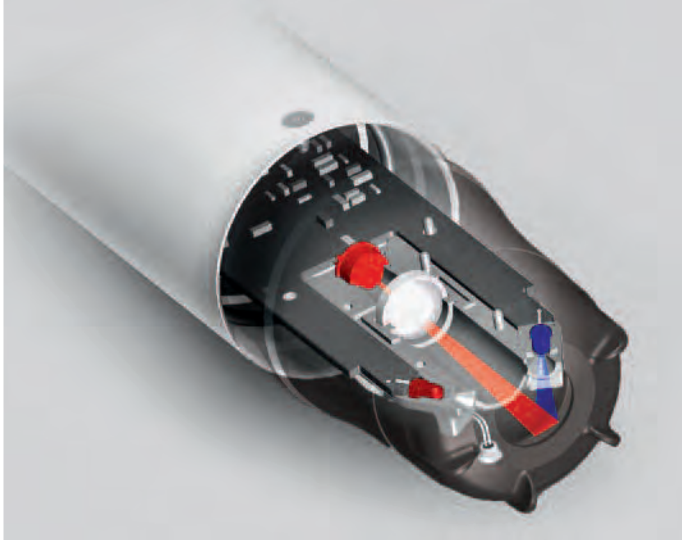
Sensor Immersion Depth	Pressure Limits at 34 m 345 kPa (112 ft.), 345 kPa (50 psi), maximum; accuracy may not be maintained at this depth
Transmission Distance	1000 m (3280 ft.) maximum when used with a termination box
Cable Length	10 m
Wetted Materials	Sensor Cap: Acrylic; Probe Body: CPVC, Polyurethane, Viton, Noryl, 316 Stainless Steel
Dimensions (D x L)	1.95 in x 10.05 in (49.53 mm x 255.27 mm)
Weight	2.2 lbs. (1 kg)

**Subject to change without notice.*

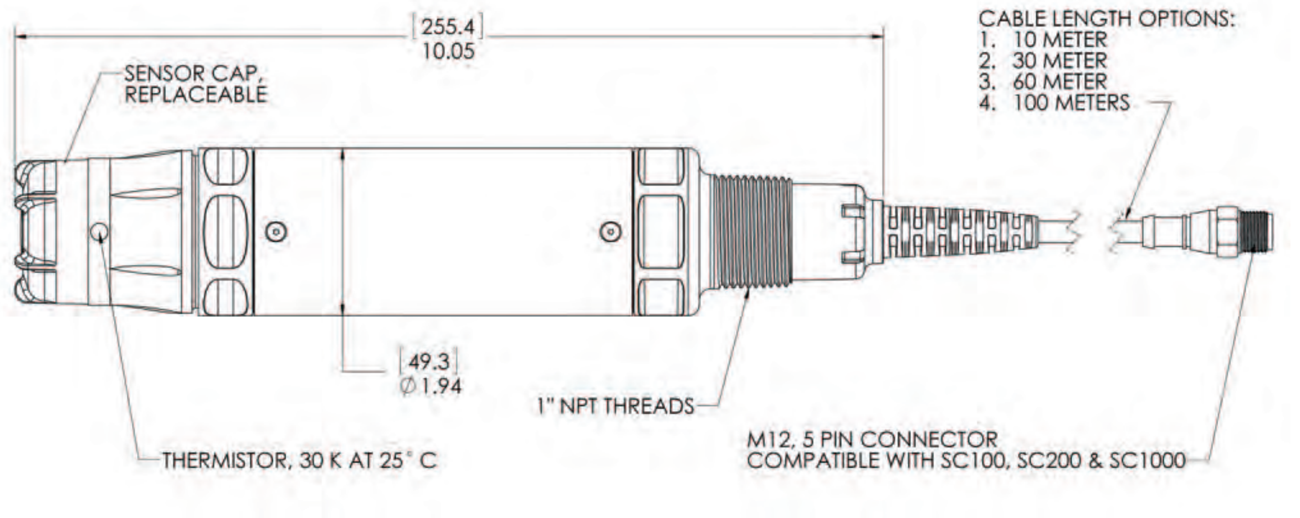
Principal of Operation

The HACH LDO sensor is coated with a luminescent material. Blue light from an LED is transmitted to the sensor surface. The blue light excites the luminescent material. As the material relaxes it emits red light. The time for the red light to be emitted is measured. Between the flashes of blue light, a red LED is flashed on the sensor and used as an internal reference.

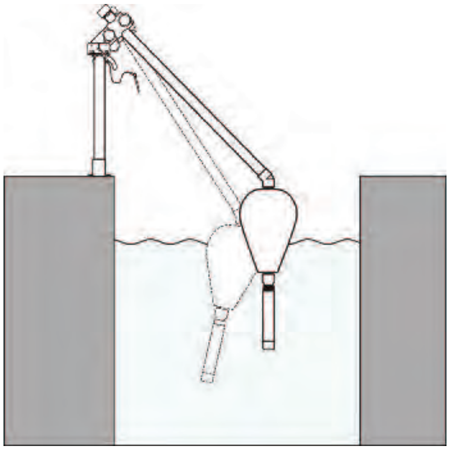
Increased oxygen in the sample decreases the time it takes for the red light to be emitted. The time measurements correlate to the oxygen concentration.



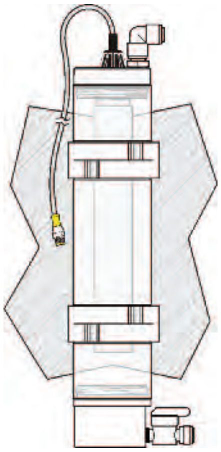
Dimensions



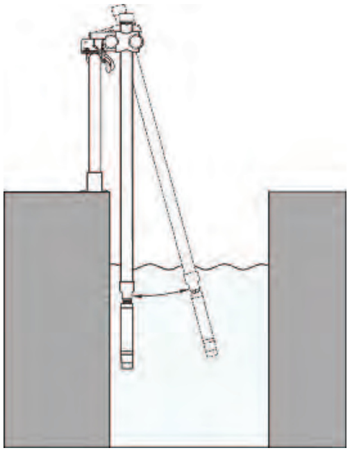
Installation / Mounting



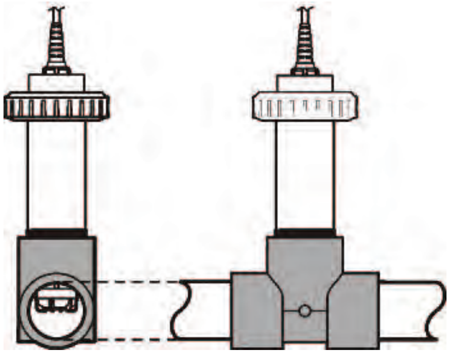
Float Mount Kit



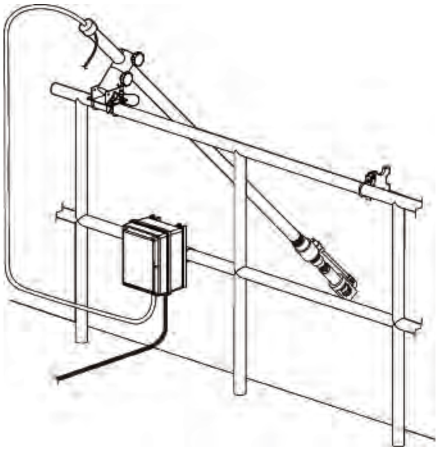
Flow Cell



Pole Mount Kit



Union Mount Kit



Air Blast Cleaning System

Ordering Information

9020000	Dissolved Oxygen: Hach LDO® Probe
9020000-UPGRADE	LDO Probe, Mounting Conversion Adapter
9020000-SC200	LDO Probe, Mounting Conversion Adapter, sc200 controller with 2 channels

Accessories

5867000	Digital Termination Box
5796000	Digital Extension Cable, 7.7 m (25 ft.)
5796100	Digital Extension Cable, 15 m (50 ft.)
5796200	Digital Extension Cable, 31 m (100 ft.)
6860000	High Output Air Blast Cleaning System, 115 Vac
6860100	High Output Air Blast Cleaning System, 230 Vac
9253500	Air Blast Hardware Components

Replacement Parts

9021100	LDO Model 2 Sensor Cap Replacement Kit

Mounting Kits

9253000	Pole Mount Kit, PVC
9253100	Ball Float Mount Kit, PVC
9257000	Union Mount Kit, PVC
9253400	Mounting Conversion Adapter, LDO Model 1 to LDO Model 2
7300800	1 NPT sc Sensors Flow Cell

Controllers

sc200 Digital Controllers

LXV404.99.00552	sc200 controllers, 2 channels, digital
LXV404.99.00542	sc200 controller, 2 channel, digital & mA input
LXV404.99.00502	sc200 controller, 1 channel, digital
LXV404.99.00512	sc200 controller, 2 channel, digital & pH/DO
LXV404.99.00522	sc200 controller, 2 channel, digital & Conductivity
LXV404.99.00532	sc200 controller, 2 channel, digital & Flow

sc1000 Digital Controllers

LXV402.99.00002	sc1000 Display Module
LXV400.99.1R572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, 110-230V
LXV400.99.1B572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, RS-485 (MODBUS), 110-230V
LXV400.99.1F572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, PROFIBUS DP, 110-230V
LXV400.99.1R582	sc1000 Probe Module, 6 sensors, 4 mA Out, 4 mA In, 4 Relays, 110-230V

HACH COMPANY World Headquarters: Loveland, Colorado USA

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Outside United States:	970-669-3050 tel	970-461-3939 fax	int@hach.com

www.hach.com

Be Right™

NITRATAX™ sc
UV Nitrate Sensors

Features and Benefits

UV Analysis—Eliminates Reagents, Sampling, and Sample Conditioning

Using advanced ultraviolet (UV) absorption technology, Hach NITRATAX sc UV Nitrate Sensors offer unprecedented simplicity, accuracy, and economy in nitrate analysis. By continuously measuring the UV light absorbed by nitrates, NITRATAX sc sensors eliminate the need for reagents, sample conditioning, and frequent calibrations.

UV Absorption Method—
Proven, Continuous, Precise

NITRATAX sc sensors rely on the principle that molecular bonds absorb ultraviolet (UV) light—in this case, nitrate (NO_3) and nitrite (NO_2) absorb UV light. As the concentration of nitrate or nitrite increases, UV absorption also increases. A built-in photometer measures the primary beam, while a second beam of UV light provides a reference standard and corrects for interference caused by turbidity and organic matter. Results are reported on the controller unit's alphanumeric display in mg/L of nitrate (NO_3) or nitrate-nitrogen (NO_3-N).

Choice of Three Models

NITRATAX plus sc—Process sensor for continuous measurement in drinking water, wastewater, or activated sludge. Turbidity compensation using reference measurement.

NITRATAX eco sc—Low cost sensor for measurement, especially for sewage treatment plants with intermittent aeration technology. Turbidity compensation using reference measurement.

NITRATAX clear sc—Process sensor for continuous measurement in clean water such as drinking water or wastewater effluent.

Self-Cleaning Sensor

With the sensor submerged in the sample stream, the detector windows are automatically cleaned by a built-in wiper that eliminate surface films or particles that can diminish accuracy.

Optional Bypass Panel

An optional Bypass Panel—or flow-through sample cell—is available for clean water applications when direct immersion in a sample stream is impractical. The Bypass Panel uses the same probes as the immersion sensors for greater flexibility.

Applications

Hach NITRATAX sc sensors are the ideal choice to ensure consistent water quality, keep discharge waters clean, comply with regulatory requirements, and safeguard the environment.

Sophisticated, yet simple, technology means the Hach NITRATAX sc UV Nitrate Sensors require little maintenance and offers remarkably low cost of operation.

Wastewater—Monitor influent, effluent, and aeration basin water. Control methanol feed and/or mixed liquor recycle denitrification process to minimize costs.

Drinking Water—Monitor nitrate levels in both influent and effluent streams before and after the disinfection process.

Agriculture—Measure and control nitrate discharges into rivers, lakes, wetlands, and other natural bodies of water.

Full-Featured "Plug and Play" Hach sc Digital Controllers

There are no complicated wiring or set up procedures with any Hach sc controller. Just plug in any combination of Hach digital sensors and it's ready to use—it's "plug and play."

One or multiple sensors—The sc controller family allows you to receive data from up to eight Hach digital sensors in any combination using a single controller.

Communications—Multiple alarm/control schemes are available using the relays and PID control outputs. Available communications include analog 4-20 mA, digital MODBUS® (RS485 and RS232) or Profibus DP protocols. (Other digital protocols are available. Contact your Hach representative for details.)

Data logger—A built-in data logger collects measurement data, calibration, verification points, and alarm history.

DW
WW
IW
E

DW = drinking water WW = wastewater municipal PW = pure water / power
IW = industrial water E = environmental C = collections FB = food and beverage

Be Right™

Specifications*

	NITRATAX plus sc	NITRATAX eco sc	NITRATAX clear sc
Measuring Principal	Reagent-free UV absorption with patented 2-beam technique		
Measuring Gap/Path Length	1, 2, and 5 mm	1 mm	5 mm
Measuring Range	0.1 to 100.0 mg/L NO_{2+3}-N (1 mm) 0.1 to 50.0 mg/L NO_{2+3}-N (2 mm) 0.1 to 25.0 mg/L NO_{2+3}-N (5 mm)	1.0 to 20.0 mg/L NO_{2+3}-N (1 mm)	0.5 to 20.0 mg/L NO_{2+3}-N (5 mm)
Detection Limits	0.1 to 100 mg/L NO_3-N	1.0 to 20 mg/L NO_3-N	0.5 to 20 mg/L NO_3-N
Accuracy	±3% of reading or ±0.5 mg/L, whichever is greater	±5% of reading or ±1.0 mg/L, whichever is greater	±5% of reading or ±0.5 mg/L, whichever is greater
Resolution	0.1 mg/L	0.5 mg/L	0.1 mg/L
Sludge Compensation	Yes	Yes	—
Measurement Interval	1 minute	5 minutes	5 minutes
Response Time (T100)	1 minute	15 minutes	5 minutes
Available with Bypass	Yes	No	Yes
Sensor Construction			
Enclosure	Stainless Steel 1.4571		Stainless Steel 1.4581
Wiper Axle	Stainless Steel 1.4104	Stainless Steel 1.4571	
Wiper	Silicon		
Measuring Window	Quartz Glass		
Functional Verification	Using standard solutions		
Service Intervals	6 months or as experience dictates		
Maintenance Required (typical)	1 hour/month	2 hours/month	1 hour/month
Operating Temperature	2 to 40°C (36 to 104°F)		
Operating Pressure	0.5 bar (7.2 psi), maximum		
Cable Length	10 m (32.8 ft.)		
Dimensions (approximate)	33.3 x 7.0 cm (13.1 x 2.8 in.)	32.3 x 7.5 cm (12.7 x 3.0 in.)	32.7 x 7.5 cm (12.7 x 3.0 in.)

**Specifications subject to change without notice.*

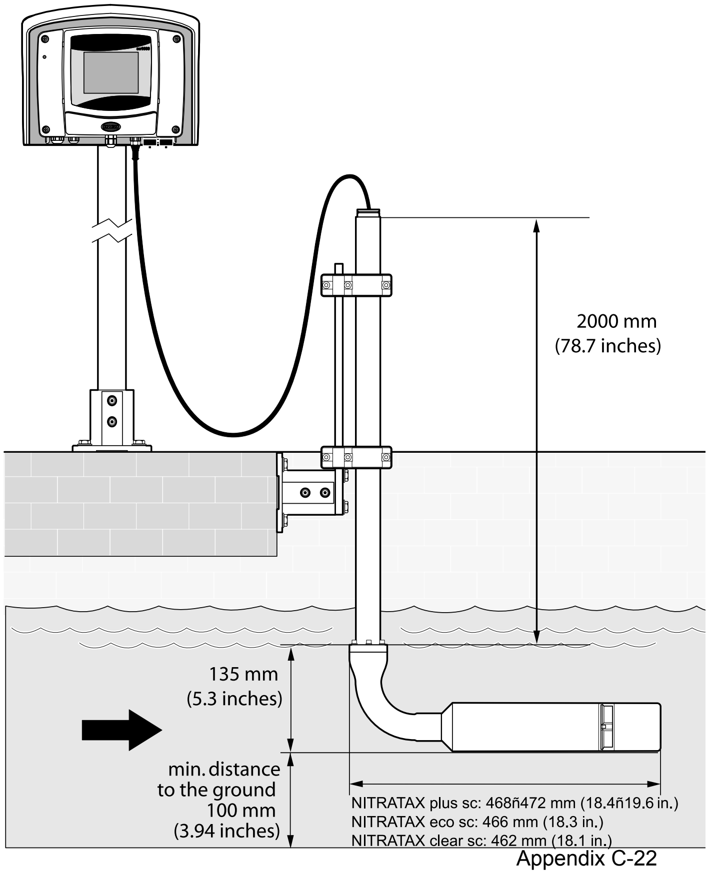
Hach NITRATAX sc UV Nitrate Sensors use UV light absorption to assess the sum of nitrates and nitrites in aqueous sample streams.

A stainless-steel sensor immersed directly in the sample stream, provide continuous readings at exceptionally low operating cost.

- *Two UV light wavelengths provide precise readings, compensating for solids and turbidity.*
- *With the sensor submerged in the sample stream, the detector windows are automatically cleaned by a built-in wiper, eliminating surface films or particles that can diminish accuracy.*

Installation Dimensions

Installation for mounting NITRATAX sc using Fixed Point Installation Kit (LZX414.00.10000).



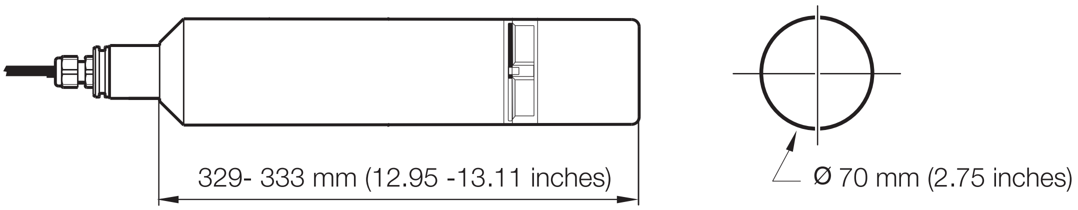
Engineering Specifications

1. The nitrate sensor shall be a continuous-reading sensor that utilizes a 2-beam ultra-violet absorption technology with a 1, 2, or 5 mm path length.
2. The measurement range shall be 0.1 to 100 mg/L NO_2-N + NO_3-N, depending on model.
3. The measurement interval shall be user-selectable from 1 to 30 minutes (unit dependent) with the ability to average up to 12 signals depending upon unit selected.
4. The sensor shall compensate for the interference effects of turbidity and organic contamination.
5. The sensor shall provide reagent-free operation without the requirements of sample conditioning.
6. The sensor shall be self-cleaning via a wiper and retain a life-long factory calibration.
7. The sensor shall be warranted for one full year against defects in material and workmanship.
8. The sensor shall be the NITRATAX plus sc, NITRATAX eco sc, or NITRATAX clear sc UV Nitrate Sensor for nitrate measurement, manufactured by Hach Company.

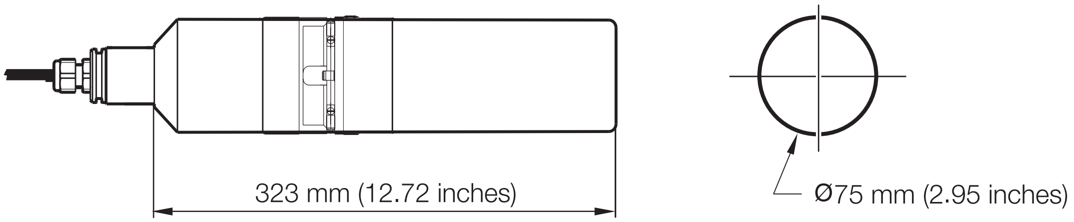
Sensor and Bypass Panel Dimensions

Hach NITRATAX sc UV Nitrate Sensors can be installed using a fixed-point installation kit. With the cable supplied, the sensor can be used in a sample stream within 10 meters (32.8 feet) of the controller.

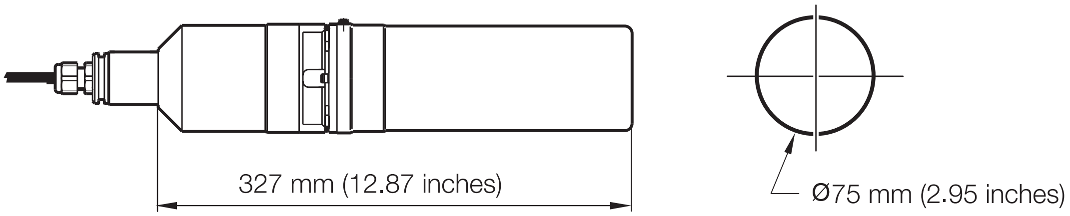
NITRATAX plus sc



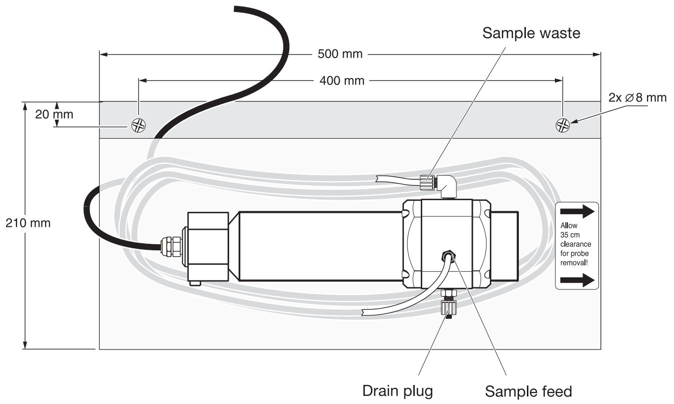
NITRATAX eco sc



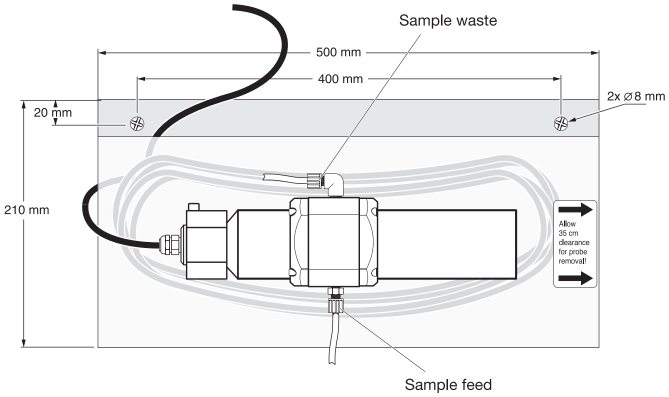
NITRATAX clear sc



NITRATAX plus sc Bypass Panel



NITRATAX clear sc Bypass Panel



Ordering Information

Sensor Selection

	NITRATAX plus sc	NITRATAX eco sc	NITRATAX clear sc
Wastewater Application			
Anoxic Zone	X	-	-
Aeration Tank	X	●	-
Plant Effluent	X	-	X
Sequencing Bath Reactor (SBR)	X	X	-
Cascade	X	●	-
Drinking Water Application			
Influent Monitoring	X	-	X
Water Blending	X	-	X
Denitrification Process	X	-	X
Outlet/Quality Control	X	-	X
Bypass/Flowthrough Cell	X	-	X

X = suitable ● = of limited suitability

NITRATAX sc UV Nitrate Analyzer Systems

2984000	NITRATAX plus sc system includes sensor with 2 mm path length, mounting hardware, and sc200 controller
2984100	NITRATAX plus sc system includes flow-through cell sensor with 2 mm path length, mounting hardware, and sc200 controller.
2984200	NITRATAX eco sc system includes sensor with 1 mm path length, mounting hardware, and sc200 controller
2984300	NITRATAX clear sc system includes sensor with 5 mm path length, mounting hardware, and sc200 controller
2984400	NITRATAX clear sc system includes flow through cell sensor with 5 mm path length, mounting hardware, and sc200 controller

Individual NITRATAX sc UV Nitrate Sensors

All sensors are equipped with 10 m (32.8 ft.) cable.

LXV417.99.10002
NITRATAX plus sc sensor, 1 mm path length

LXV417.99.20002
NITRATAX plus sc sensor, 2 mm path length

LXV417.99.50002
NITRATAX plus sc sensor, 5 mm path length

LXV420.99.50002
NITRATAX clear sc sensor, 5 mm path length

LXV415.99.10002
NITRATAX eco sc sensor, 1 mm path length

Accessories

LZX414.00.10000
Mounting hardware for sensor

LZX869	Flow-through cell for NITRATAX plus sc-sensors, 2 mm path length
LZX867	Flow-through cell for NITRATAX plus sc-sensors, 5 mm path length
LZX866	Flow-through cell for NITRATAX clear sc-sensors, 5 mm path length
LCW828	Calibration standard 25 mg/L NO_3 (5.56 mg/L NO_3-N)
LCW825	Calibration standard 50 mg/LNO_3 (11.3 mg/L NO_3-N)
LCW826	Calibration standard 100 mg/L NO_3 (22.6 mg/L NO_3-N)
LCW827	Calibration standard 200 mg/L NO_3 (45.2 mg/L NO_3-N)
LCW863	Calibration standard 400 mg/L NO_3 (90.4 mg/L NO_3-N)
LZX148	Spare wiper blades for 1 mm Nitratax, pk/5
LZX012	Spare wiper blades for 2 mm Nitratax, pk/5
LZX117	Spare wiper blades for 5 mm Nitratax, pk/5

Cable Accessories

5867000	Junction box for extension cables
5796000	Extension cable, 7.6 m (25 ft.)
5796100	Extension cable, 15.2 m (50 ft.)
5796200	Extension cable, 30.5 m (100 ft.)

**This sensor requires a Hach sc digital controller.
Ask your Hach representative for more information.**

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In the interest of improving and updating its equipment, Hach Company reserves the right to alter specifications to equipment at any time.

At Hach, it's about learning from our customers and providing the right answers. It's more than ensuring the quality of water—it's about ensuring the quality of life. When it comes to the things that touch our lives...

Keep it pure.

Make it simple.

Be right.

For current price information, technical support, and ordering assistance, contact the Hach office or distributor serving your area.

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Be Right™

Differential pH and ORP Sensors

Hach Digital pHD sc sensors are available in convertible (PEEK® or Ryton®), insertion, and sanitary body styles. Three electrodes are used in these sensors to increase measurement accuracy and eliminate sensor ground loops.

Features and Benefits

Differential Electrode Measurement Technique

This field-proven technique uses three electrodes instead of the two normally used in conventional pH sensors. Process and reference electrodes measure the pH differentially with respect to a third ground electrode. The end result is unsurpassed measurement accuracy, reduced reference junction potential, and elimination of sensor ground loops. These sensors provide greater reliability, resulting in less downtime and maintenance.

Patented Technology

The former GLI, now a Hach Company brand, invented the Differential Electrode Technique for pH measurement in 1970. The pHD™ sensor series (U.S. Patent Number 6395158B1, dated May 28, 2002) takes this field-proven technology to a new level.

Replaceable Salt Bridge/Protector

The unique, replaceable salt bridge holds an extraordinary volume of buffer to extend the working life of the sensor by protecting the reference electrode from harsh process conditions. The salt bridge simply threads onto the end of the sensor if replacement is needed.

Built-in Encapsulated Preamp

Encapsulated construction protects the sensor's built-in preamp from moisture and humidity, ensuring reliable sensor operation. The preamp in the pHD analog sensor produces a strong signal, enabling the sensor to be located up to 1000 m (3280 ft.) from the analyzer.

Durable Body Materials

Both the digital and analog pH and ORP differential sensors feature a durable PEEK® body for chemical compatibility with most process solutions. For less aggressive solutions, Hach offers a Ryton® sensor in a convertible style for pH and ORP measurement. A sensor with a stainless steel body is available for immersion applications.

Digital Electronics Modules

Sensors are available with integral digital electronics or with a gateway module for high temperature (above 70ºC) applications.

Versatile Mounting Styles

Sensors are available in four mounting styles—convertible, insertion, immersion, and sanitary. Please turn to page 5 for more information.

Full Featured "Plug and Play" sc100 Digital Controller

There's no complicated wiring or set up procedures with the Hach sc100 controller. Just plug in any Hach digital sensor and it's ready to use—it's "plug and play."

One or two sensors—Use the sc100 Digital Controller to receive data from up to two Hach digital sensors in any combination.

Communications—Multiple alarm/control schemes are available using three relays and two PID control outputs. Communications use analog 4-20 mA and digital MODBUS®/RS485, MODBUS®/RS232 protocols. (Other digital protocols are available. Contact your Hach representative for details.) Every sc100 controller is equipped with wireless communication through an infrared port.

Data logger—A built-in data logger collects measurement data, calibration, verification points, and alarm history for up to 6 months.

DW = drinking water WW = wastewater municipal PW = pure water / power
IW = industrial water E = environmental C = collections FB = food and beverage

Specifications*

pH Sensors

Most pH applications fall in the 2.5 to12.5 pH range. A Hach pHD sc Differential pH sensor with the wide-range glass process electrode performs exceptionally well in this range. Some industrial applications require accurate measurement and control below 2 or above 12 pH. In these special cases, please contact Hach Technical Support for further details.

Measuring Range
-2 to 14 pH

Sensitivity
± 0.01 pH

Stability
0.03 pH per 24 hours, non-cumulative

Operating Temperature
Digital Sensor: -5 to 70°C (23 to 158°F)
Analog Sensor with Digital Gateway: -5 to 105°C (23 to 221°F)
Immersion Sensor: 0 to 50°C (32 to 122°F)

Flow Rate
3 m (10 ft.) per second, maximum

Sensor Pressure/Temperature Limits
Digital: 6.9 bar at 70°C (100 psi at 158°F)
Analog: 6.9 bar at 105°C (100 psi at 221°F)

Built-in Temperature Element
NTC 300 ohm thermistor for automatic temperature compensation and analyzer temperature readout

Transmission Distance
100 m (328 ft.), maximum
1000 m (3280 ft.), maximum when used with a termination box

Sensor Cable (integral)
4 conductor cable with one shield and polyurethane jacket; rated to 105°C (221°F); 10 m (33 ft.) standard length

Wetted Materials
PEEK® or Ryton® (PVDF), salt bridge of matching material with Kynar® junction, glass process electrode, titanium ground electrode, and Viton® O-ring seals

(pH sensor with optional HF-resistant glass process electrode has 316 stainless steel ground electrode, and perfluoroelastomer wetted O-rings; consult factory for other available wetted O-ring materials)

ORP (Redox) Sensors

For best ORP measuring results in solutions containing zinc, cyanide, cadmium or nickel, Hach recommends using the pHD sc ORP sensor equipped with an optional gold electrode.

Measuring Range
-1500 to +1500 mV

Sensitivity
± 0.5 mV

Stability
2 mV per 24 hours, non-cumulative

Operating Temperature
Digital Sensor: -5 to 70°C (23 to 158°F)
Analog Sensor with Digital Gateway: -5 to 105°C (23 to 221°F)
Immersion Sensor: 0 to 50°C (32 to 122°F)

Flow Rate
3 m (10 ft.) per second, maximum

Sensor Pressure/Temperature Limits
Digital: 6.9 bar at 70°C (100 psi at 158°F)
Analog: 6.9 bar at 105°C (100 psi at 221°F)

Built-in Temperature Element
NTC 300 ohm thermistor for analyzer temperature readout only—no automatic temperature compensation necessary for ORP measurement

Transmission Distance
100 m (328 ft.), maximum
1000 m (3280 ft.), maximum when used with a termination box

Sensor Cable (integral)
4 conductor cable with one shield and polyurethane jacket; rated to 105°C (221°F); 10 m (33 ft.) standard length

Wetted Materials
PEEK® or Ryton® (PVDF), salt bridge of matching material with Kynar® junction, glass and platinum (or plastic and gold) process electrode, titanium ground electrode, and Viton® O-ring seals

**Specifications subject to change without notice.*

PEEK® is a registered trademark of ICI Americas, Inc.; Ryton® is a registered trademark of Phillips 66 Co.; Kynar® is a registered trademark of Pennwalt Corp.; Viton® is a registered trademark of E.I. DuPont de Nemours + Co.

Engineering Specifications

PEEK® Sensor

1. The pH or ORP sensor shall be of Differential Electrode Technique design using two measuring electrodes to compare the process value to a stable internal reference standard buffer solution. The standard electrode shall have non-flowing and fouling-resistant characteristics.
2. The sensor shall have a hex-shaped body to facilitate mounting, and shall be constructed of PEEK® material for exceptional chemical resistance and mechanical strength. This material shall enable the sensor to be installed in metal fittings without leakage usually caused by heating and cooling cycles when dissimilar materials are threaded together.
3. The sensor shall have a:
    a) Convertible body style featuring 1-inch NPT threads on both ends to mount into a standard 1-inch pipe tee, into a Hach adapter pipe for union mounting with a standard 1-1/2 inch tee, or onto the end of a pipe for immersion into a vessel.
    b) Insertion body style featuring 1-inch NPT threads only on the cable end to mount into a Hach ball valve hardware assembly, enabling the sensor to be inserted into or retracted from the process without stopping the process flow.
    c) Sanitary body style featuring an integral 2-inch flange to mount into a Hach 2-inch sanitary tee. The sanitary body style sensor shall include a special cap and EDPM compound gasket for use with the Hach sanitary hardware.
4. The built-in electronics of the sensor shall be completely encapsulated for protection from moisture and humidity.
5. The sensor shall have a built-in preamplifier to enable the signal to be transmitted up to 100 m (328 ft.) with standard cabling and up to 1000 m (3280 ft.) with a termination box.
6. The sensor signal shall have an integral temperature sensor. The pH sensor shall automatically compensate measured values for changes in process temperature.
7. The ORP sensor shall include a titanium ground electrode (standard) to eliminate ground loop currents in the measuring electrodes.
8. The sensor shall be Hach Company Model pHD sc or pHD for pH or ORP measurement.

Ryton® Sensor

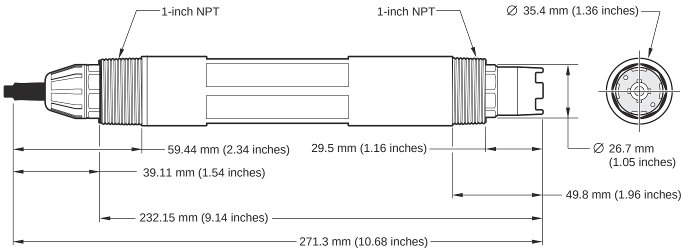
1. The pH or ORP sensor shall be of Differential Electrode Technique design using two measuring electrodes to compare the process value to a stable internal reference standard buffer solution. The standard electrode shall have non-flowing and fouling-resistant characteristics.
2. The sensor shall have a hex-shaped body to facilitate mounting, and shall be constructed of Ryton® material for exceptional chemical resistance and mechanical strength. This material shall enable the sensor to be installed in metal fittings without leakage usually caused by heating and cooling cycles when dissimilar materials are threaded together.
3. The sensor shall have a convertible body style featuring 1-inch NPT threads on both ends to mount into a standard 1-inch pipe tee, into a Hach adapter pipe for union mounting with a standard 1-1/2 inch tee, or onto the end of a pipe for immersion into a vessel.
4. The built-in electronics of the sensor shall be completely encapsulated for protection from moisture and humidity.
5. The sensor shall have a built-in preamplifier to enable the signal to be transmitted up to 100 m (328 ft.) with standard cabling and up to 1000 m (3280 ft.) with a termination box.
6. The sensor signal shall have an integral temperature sensor. The pH sensor shall automatically compensate measured values for changes in process temperature.
7. The ORP sensor shall include a titanium ground electrode (standard) to eliminate ground loop currents in the measuring electrodes.
8. The sensor shall be Hach Company Model pHD sc or pHD for pH or ORP measurement.

Stainless Steel Sensor

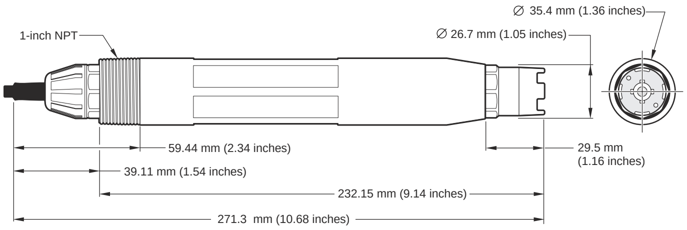
1. The pH or ORP sensor shall be of differential electrode technique design using two measuring electrodes to compare the process value to a stable internal reference standard buffer solution. The standard electrode shall have non-flowing and fouling-resistant characteristics.
2. The sensor shall be capable of chain mounting for immersion applications, and shall be constructed of 316 stainless steel.
3. The built-in electronics of the sensor shall be completely encapsulated for protection from moisture and humidity.
4. The sensor shall have a built-in preamplifier to enable the signal to be transmitted up to 100 m (328 ft.) with standard cabling and up to 1000 m (3280 ft.) with a termination box.
5. The sensor signal shall have an integral temperature sensor to automatically compensate measured values for changes in process temperature.
6. The sensor shall include a titanium ground electrode (standard) to eliminate ground loop currents in the measuring electrodes.
7. The sensor shall be Hach Company Model pHD sc or pHD for pH or ORP measurement.

Dimensions

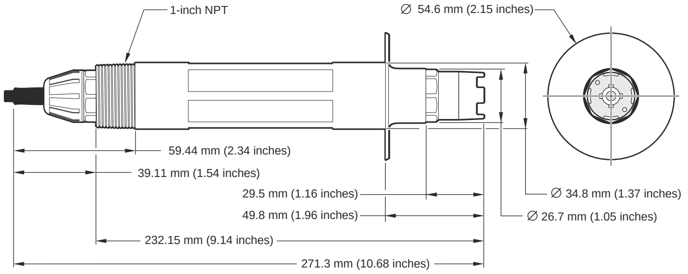
Convertible Style



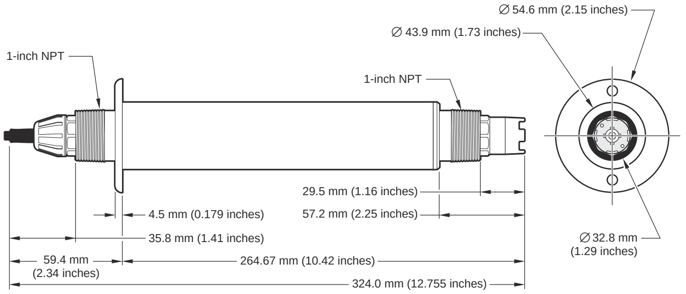
Insertion Style



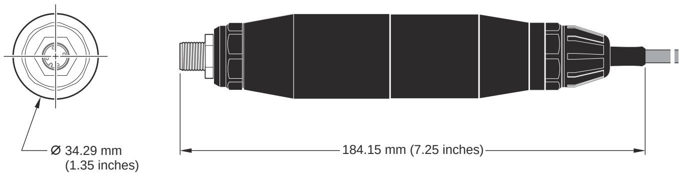
Sanitary Style



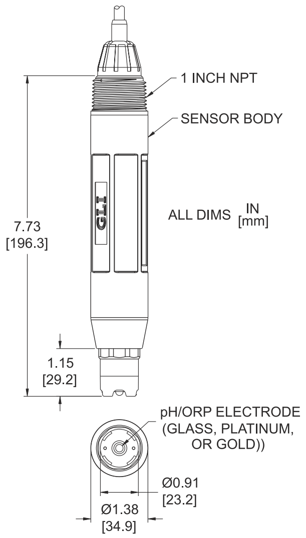
Immersion Style



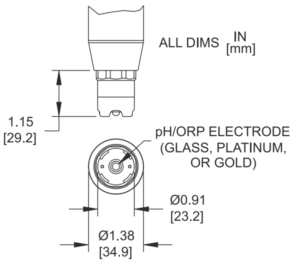
Digital Gateway



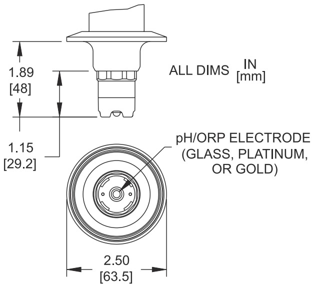
Analog Convertible Style



Analog Insertion Style



Analog Sanitary Style



Ordering Information

pHD sc Digital Differential pH/ORP Sensors

All digital sensors include built-in digital electronics and integral 10 m (33 ft.) cable terminated with connector for the sc100 digital controller. Body styles:

- *Convertible – 1-inch NPT threads at both ends, designed for tee-mounting or other flow through mountings, and pipe mounting for immersion*
- *Insertion – no threads on the electrode end, designed for use with insertion valve assembly*
- *Sanitary – 2-inch flange for a tri-clover style fitting*
- *Immersion – used with chain mounting or pipe mounting*

pH Sensors

Product Number	*Body Material*	*Body Style*	*Electrode Material*	*Max Temp*
DPD1P1	PEEK[1]	Convertible	Glass, General Purpose	70°C (158°F)
DPD1P3	PEEK[1]	Convertible	Glass, HF-resistant	70°C (158°F)
DPD2P1	PEEK[1]	Insertion	Glass, General Purpose	70°C (158°F)
DPD3P1	PEEK[1]	Sanitary	Glass, General Purpose	70°C (158°F)
DPD1R1	Ryton[2]	Convertible	Glass, General Purpose	70°C (158°F)
DPD1R3	Ryton[2]	Convertible	Glass, HF-resistant	70°C (158°F)
DPS1	Stainless Steel	Immersion	Glass, General Purpose	50°C (122°F)

[1] *Polyetheretherketone* [2] *Polyphenelene Sulfide*

ORP Sensors

Product Number	*Body Material*	*Body Style*	*Electrode Material*	*Max Temp*
DRD1P5	PEEK[1]	Convertible	Platinum	70°C (158°F)
DRD1P6	PEEK[1]	Convertible	Gold	70°C (158°F)
DRD2P5	PEEK[1]	Insertion	Platinum	70°C (158°F)
DRD1R5	Ryton[2]	Convertible	Platinum	70°C (158°F)
DRD1R6	Ryton[2]	Convertible	Gold	70°C (158°F)
DRS5	Stainless Steel	Immersion	Platinum	50°C (122°F)

[1] *Polyetheretherketone* [2] *Polyphenelene Sulfide*

Digital Gateway

6120500	Digital Gateway, convert pHD analog sensors to digital output for connecting to sc100 digital controller

pHD Analog Sensors

All analog sensors include built-in preamplifier and integral 4.5 m (15 ft.) cable terminated with stripped and tinned wires.

Definitions of body styles:

- *Convertible – 1-inch NPT threads at both ends, designed for tee-mounting or other flow through mountings, and pipe mounting for immersion*
- *Insertion – has no threads on the electrode end, designed for use with insertion valve assembly*
- *Sanitary – has a 2-inch flange for a Tri-Clover style fitting*

pH Sensors

Product Number	*Body Material*	*Body Style*	*Electrode Material*	*Max Temp*
PD1P1	PEEK[1]	Convertible	Glass, General Purpose	95°C (203°F)
PD1P3	PEEK[1]	Convertible	Glass, HF-resistant	95°C (203°F)
PD2P1	PEEK[1]	Insertion	Glass, General Purpose	95°C (203°F)
PD3P1	PEEK[1]	Sanitary	Glass, General Purpose	95°C (203°F)
PD1R1	Ryton[2]	Convertible	Glass, General Purpose	95°C (203°F)
PD1R3	Ryton[2]	Convertible	Glass, HF-resistant	95°C (203°F)

[1] *Polyetheretherketone* [2] *Polyphenelene Sulfide*

ORP Sensors

Product Number	*Body Material*	*Body Style*	*Electrode Material*	*Max Temp*
RD1P5	PEEK[1]	Convertible	Platinum	95°C (203°F)
RD1P6	PEEK[1]	Convertible	Gold	95°C (203°F)
RD2P5	PEEK[1]	Insertion	Platinum	95°C (203°F)
RD1R5	Ryton[2]	Convertible	Platinum	95°C (203°F)
RD1R6	Ryton[2]	Convertible	Gold	95°C (203°F)

[1] *Polyetheretherketone* [2] *Polyphenelene Sulfide*

Ordering Information *continued*

pHD sc Digital and pHD Analog Sensor Accessories

Cables

Extension cables are used only with digital sensors or digital gateways when connecting to the sc100 Digital Controller.

61224-00	Digital Extension Cable, 1 m (3.2 ft.)
57960-00	Digital Extension Cable, 7.7 m (25 ft.)
57961-00	Digital Extension Cable, 15 m (50 ft.)
57962-00	Digital Extension Cable, 31 m (100 ft.)

Interconnect cables are used only with analog sensors, junction box, and controller.

1W11-00	Analog Interconnect Cable, order per foot

Digital Termination Box

Required when the length of cable between the digital sensor/digital gateway and sc100 Digital Controller is between 100 m (328 ft.) and 1000 m (3280 ft.)

58670-00	Digital Termination Box

Analog Junction Box

Required when the length of cable between the analog sensor and analog controller is greater than standard length of sensor cable. Each junction box includes terminal strip and gasket.

60A2053	Junction Box, Surface-mount, aluminum (includes mounting hardware)
60A9944	Junction Box, Pipe-mount, PVC (for 1/2-inch diameter pipe, includes mounting hardware)
60G2052	Junction Box, Pipe-mount, PVC (for 1-inch diameter pipe, includes mounting hardware)
76A4010-001	Junction Box, NEMA 4X (no mounting hardware included)

Protector for Convertible style sensor

1000F3374-002	PEEK protector
1000F3374-003	Ryton protector

Salt Bridges

The double junction salt bridge on the standard cell of all Hach pHD sensors is field-replaceable. Each salt bridge has a ceramic inner junction, Viton® O-ring, and contains binary, equi-transferrant fill solution. Salt bridges are shipped in a salt solution.

Product Number	*pHD sc and pHD Sensor Body Material*	*Salt Bridge Materials*	
		Body	*Outer Junction*
SB-P1SV	PEEK	PEEK	Kynar (PVDF)
SB-P2SV	PEEK	PEEK	Ceramic
SB-P1SP[1]	PEEK	PEEK	Kynar (PVDF)
SB-R1SV	Ryton	Ryton	Kynar (PVDF)

[1] *Special perfluoroelastomer O-ring in place of the Viton® O-ring*

Cleaning Systems for pHD sc and pHD Sensors

Self-Contained Air Blast Cleaning System
Includes Kynar® (PVDF) washer head with 7.6 m (25 ft.) tubing for air delivery, a quick-disconnect tube fitting, and a compressor housed in a NEMA 4X enclosure.

1000A3335-005	For 115 VAC operation
1000A3335-006	For 230 VAC operation

Air/Water Blast Cleaning Washer Head
Intended only for immersion applications with a user-supplied air or water wash system.

1000A3335-004	Kynar (PVDF) washer head includes 1/4-inch barb fitting

pHD sc Digital and pHD Analog Sensor Reagents and Standards

25M1A1025-115	Standard Cell Solution, to replenish standard cell chamber in Hach pHD sensors while replacing salt bridge, 500 mL
25M8A1002-101	Gel Powder, for high temperature applications, 2 g

pH Buffers

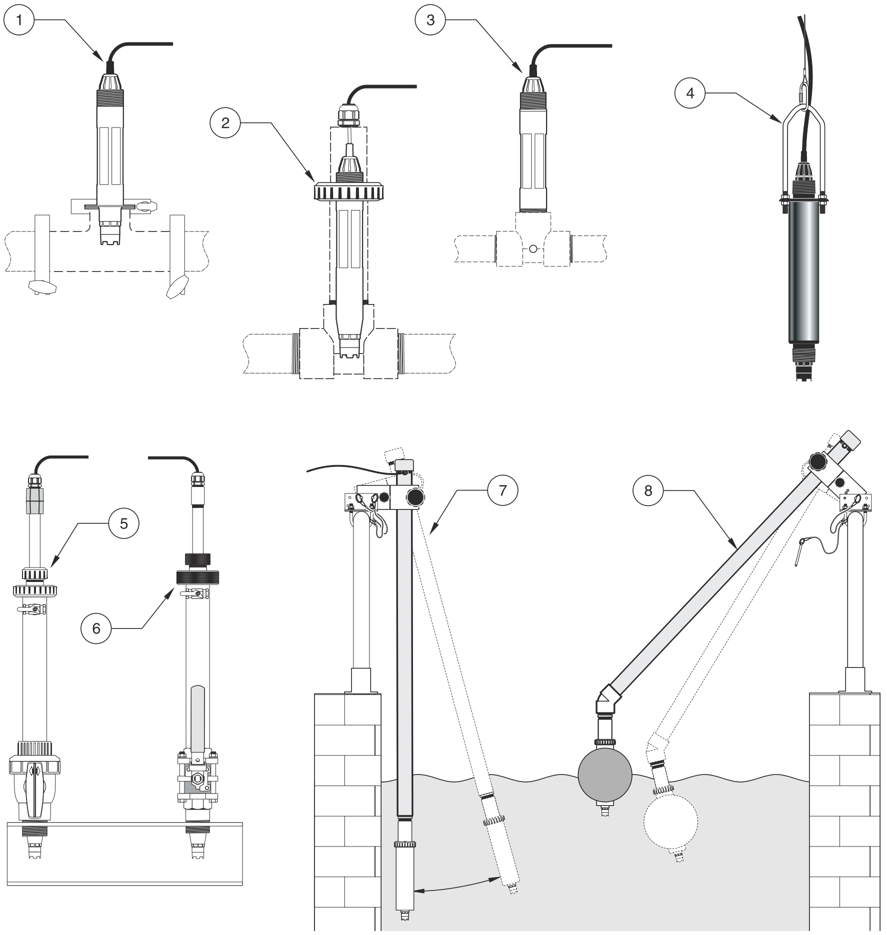
Product Number	*Description*	*Volume*
22835-49	pH 7	500 mL (1 pint)
22834-49	pH 4	500 mL (1 pint)
22836-49	pH 10	500 mL (1 pint)

ORP Reference Solutions (in resealable plastic bottles)

Product Number	*Description*	*Volume*
25M2A1001-115	200 mV	500 mL (1 pint)
25M2A1002-115	600 mV	500 mL (1 pint)

Ordering Information *continued*

Mounting Hardware for pHD sc Differential Sensors



1. Sanitary mount
2. Union mount
3. Flow-through mount
4. Hanging stainless steel sensor with the bail
5. PVC Insertion mount
6. Stainless steel insertion mount
7. Immersion mount
8. Immersion mount, ball float

Sanitary Mount

MH018S8SZ	316 SS

Includes 2-inch sanitary tee and heavy-duty clamp. Special cap and EPDM compound gasket are supplied with sensor but can be separately ordered.

Union Mount

61313-00	CPVC
61314-00	316 SS

Includes standard 1-1/2 inch tee, special union pipe with adapter, sealing hub, and lock ring in respective material, and Viton® O-ring.

Flow-through Mount

MH334N4NZ	CPVC
MH314N4MZ	316 SS

Includes a standard 1-inch tee in respective material.

Insertion Mount

Digital		*Analog*	
61367-00	CPVC	**MH736M4MZ**	CPVC
61368-00	316 SS	**MH716M4MZ**	316 SS

Includes a 1-1/2 inch ball valve in respective material, 1-1/2 inch NPT close nipple, sensor adapter with two Viton® O-rings and wiper, extension pipe, pipe adapter, back tube, and lock ring.

Immersion Mount

Standard Hardware

Digital		*Analog*	
61364-00	CPVC	**MH434A00B**	CPVC
61365-00	316 SS	**MH414A00B**	316 SS

Includes 1-inch diameter by 4 ft. long pipe and 1-inch x 1-inch NPT coupling in respective material. (Pipe-mount junction box with terminal strip included in analog hardware.)

Handrail Hardware

MH236B00Z	CPVC

Includes 1-1/2 inch diameter by 7.5 ft. long CPVC pipe, and a unique swivel/pivot/ pipe clamp assembly.

Chain Mount Hardware

2881900	316 ss

Includes stainless steel bail, nuts, and washers. Does not include chain. To be used with stainless steel immersion sensor only.

NOTE

Contact Hach Technical Support or your Hach representative for information about retro fit hardware for existing installations.

To complete your pH and ORP measurement system, choose the sc100 or the sc1000 controller...

Model sc100 Controller

(see Lit. #2463)

LXV401.52.00002	sc100 Controller Standard
LXV401.52.01002	sc100 Controller with RS-232 MODBUS®
LXV401.52.02002	sc100 Controller with RS-485 MODBUS®

Model sc1000 Controller

(see Lit. #2403)

LXV402.99.00002	sc1000 Display Module
LXV400.99.1R572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, 110-230V
LXV400.99.1B572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, RS-485 (MODBUS), 110-230V
LXV400.99.1F572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, PROFIBUS DP, 110-230V
LXV400.99.1R582	sc1000 Probe Module, 6 sensors, 4 mA Out, 4 mA In, 4 Relays, 110-230V

Lit. No. 2467
B53 Printed in U.S.A.

At Hach, it's about learning from our customers and providing the right answers. It's more than ensuring the quality of water—it's about ensuring the quality of life. When it comes to the things that touch our lives...

Keep it pure.

Make it simple.

Be right.

For current price information, technical support, and ordering assistance, contact the Hach office or distributor serving your area.

In the United States, contact:

HACH COMPANY World Headquarters
P.O. Box 389
Loveland, Colorado 80539-0389
U.S.A.
Telephone: 800-227-4224
Fax: 970-669-2932
E-mail: orders@hach.com
www.hach.com

U.S. exporters and customers in Canada, Latin America, sub-Saharan Africa, Asia, and Australia/New Zealand, contact:

HACH COMPANY World Headquarters
P.O. Box 389
Loveland, Colorado 80539-0389
U.S.A.
Telephone: 970-669-3050
Fax: 970-461-3939
E-mail: intl@hach.com
www.hach.com

In Europe, the Middle East, and Mediterranean Africa, contact:

HACH + LANGE Europe
Dr. Bruno Lange GmbH & Co. KG
Willstätterstraße 11
D-40549 Düsseldorf
GERMANY
Tel: +49 (0) 211 5288-0
Fax: +49 (0) 211 5288-143
E-mail: info@hach-lange.de
www.hach-lange.com

Be Right™

AISE sc PROBE WITH RFID TECHNOLOGY

Applications

- Wastewater

Single ISE probe for the on-line measurement of Ammonium provides trending information with minimal maintenance at an affordable price.

Cost-Effective Trending Information

The AISE sc Sensor utilizes ion selective electrode (ISE) technology to provide your plant with high level trending information while saving money by eliminating the need for reagents and sample preparation.

Minimal Maintenance with Simple Cartridge Replacement

The sensor operates within in a CARTRICAL™ cartridge that comes factory calibrated so little maintenance is necessary. Cartridge replacement is simple: unscrew the old cartridge, plug in the new one, and the sensor is ready for measurement. Using RFID* technology, the factory calibration is automatically identified after replacing the cartridge.

Simple, Accurate Calibration

Easy to perform, fail-safe calibration corrections compensate for naturally occuring calibration drift in ISE instruments. An advanced menu structure allows you to perform corrections without manual entry of values via Ethernet, SD card or Bluetooth®.

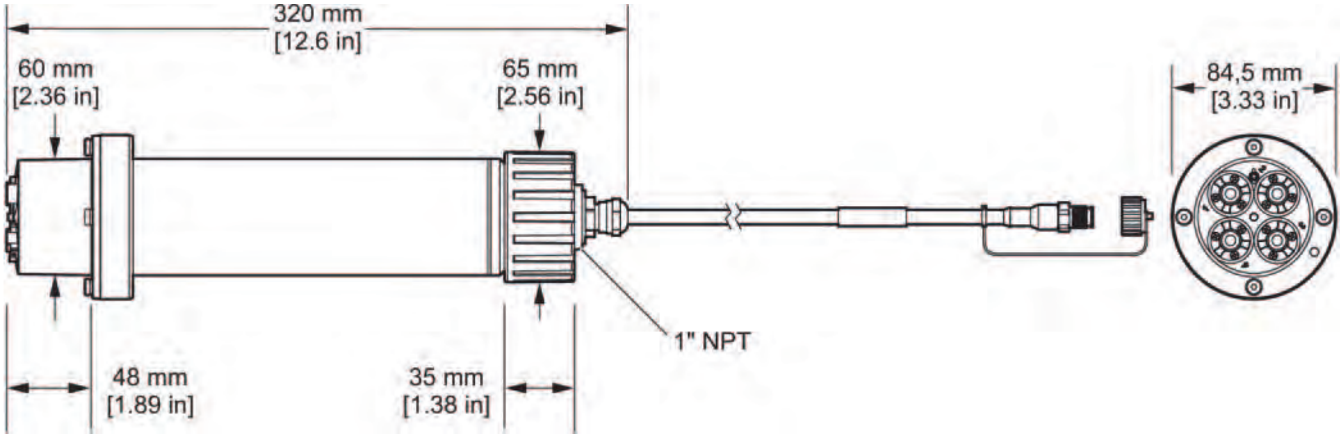
**RFID version available only in US, EU, Canada, Australia, New Zealand, Croatia, Cyprus and Turkey.*

Specifications*

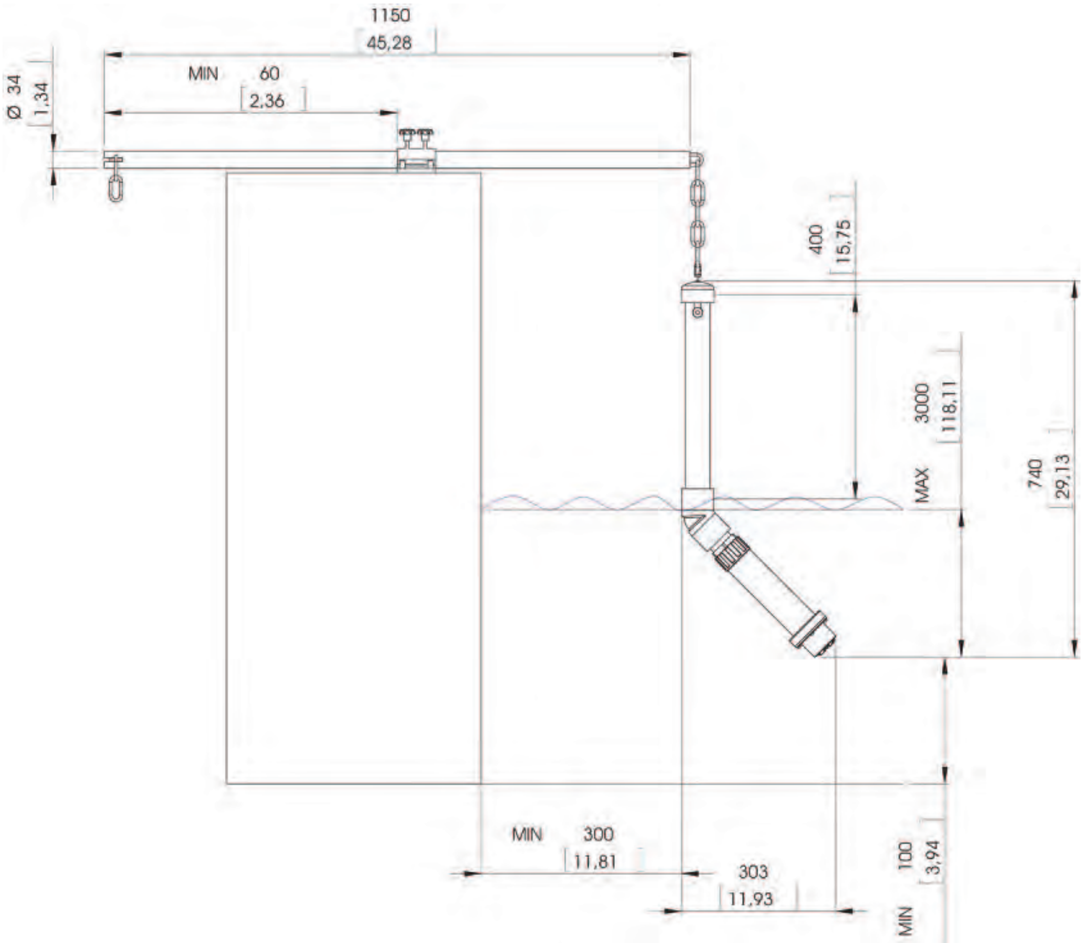
Measurement Method	Potentiometric ion-selective measurement
Range	0 - 1000 mg/L NH_4–N
pH Range	5 to 9 pH
Accuracy	5 % of measured value +0.2 mg/L (with standard solutions) NH_4–N
Response Time	< 3 min
Calibration Method	With CARTRICAL plus technology: automatic import of factory calibration data from cartridge to probe by RFID; 1 and 2 point matrix correction
Sample Temperature	2 to 40 °C (35 to 104 °F)
Operating Temperature Range	-4 to 113 °F
Sensor Cartridge	With CARTRICAL plus technology: compact housing containing calibrated electrodes for ammonium, potassium, reference system and temperature sensor, all calibrated to each other; typical lifetime 6 months
Flow	< 4 m/s max.
Material	Cartridge: Stainless steel (1.4571), PVC, POM, ABS, NBR
Measuring Interval	Continuous
Lower Limit of Detection (LOD)	0.2 mg/L NH_4–N
Dimensions (D x L)	3.33 in x 12.6 in (84.5 mm x 320 mm)
Sensor Immersion Depth	1.0 to 10 ft
Installation Angle	45 ° ±15 ° (vertical in flow direction)
Cable Length	Standard: 10 m / 32.8 ft extension cables available as an option in the following lengths: 5, 10, 15, 20, 30, 50 m (16.4, 32.8, 49.2, 65.6, 98.4, 164 ft); 100 m (328 ft) max. overall length
Controller Compatibility	sc200, sc1000
Process Connection	1 inch thread
Protection Class	IP 68
Sample Pressure	0.3 bar max.
Storage Conditions	5 to 40 °C (41 to 104 °F) sensor cartridge
Weight	5.25 lbs. (2.38 kg)

**Subject to change without notice.*

Dimensions



Installation / Mounting



Ordering Information

LXV440.99.10002	AISE sc ISE Ammonium Probe with RFID* Technology
LXV440.99.10012	AISE sc ISE Ammonium Probe

Mounting Hardware

6184900	Rail Mount Kit (PVC) for ISE sensors
LZX914.99.12400	Chain mounting for ISE sensors (PVC)
LZX414.99.80000	Wall mount kit (stainless steel) for ISE sensors

Cartridge

LZY694	CARTRICAL sensor cartridge for AN-ISE sc/AISE sc/NISE sc

Air Cleaning Systems (Optional)

LZY706	Cleaning unit for AN-ISE sc/AISE sc/NISE sc
6860000	High Output Air Blast Cleaning System, 115 Vac
6860100	High Output Air Blast Cleaning System, 230 Vac

Controllers

LXV404.99.00552	sc200 controllers, 2 channels, digital
LXV400.99.10082	sc1000 Probe Module, 6 Sensors, 100-240 Vac
LXV402.99.00002	sc1000 Display Module

**RFID = Radio- Frequency Identification.*

RFID version available only in US, EU, Canada, Australia, New Zealand, Croatia, Cyprus and Turkey.

HACH COMPANY World Headquarters: Loveland, Colorado USA

United States: 800-227-4224 tel 970-669-2932 fax orders@hach.com
Outside United States: 970-669-3050 tel 970-461-3939 fax int@hach.com
hach.com

LIT2807
C13 Printed in U.S.A.

DATA SHEET

sc1000™ Multi-parameter Universal Controller

Controller—Multi-Parameter

Features and Benefits

Modular System

The Hach sc1000 Multi-parameter Universal Controller is a fully modular system consisting of a Display Module and one or more Probe Modules.

Probe Module—Each sc1000 Probe Module provides power to the system and can accept up to 8 digital sensors. Probe Modules can be networked together to accommodate many more sensors attached to the same network.

Display Module—The sc1000 Display Module is a full-featured controller with a large color touch-screen display. The intuitive, easy to use interface can be used for any number of parameters. One Display Module controls either a single Probe Module or a number of Probe Modules connected by a digital network. The Display Module is fully portable and can be disconnected and moved anywhere within the network.

"Plug and Play" Operation

There's no complicated wiring or set up procedures with the sc1000 controller. Just plug the sensor into a Probe Module and it's ready for use without special ordering or software configuration.

Mix and Match Digital Sensors

The digital sensors that can be plugged into the Probe Module can be any from Hach's line of digital sensors—dissolved oxygen, pH, ORP, conductivity, turbidity, suspended solids, nitrate, etc. Use them in any combination.

Flexible Communication Options

Communication and relay options for the sc1000 controller can be configured to suit any situation. Standard configurations for a single Probe Module include;

- *up to 4 potential free relay contacts for alarm and control functions,*
- *up to 12 analog outputs for measured values,*
- *up to 12 digital or analog inputs from instruments (i.e., flow or pressure sensors),*
- *field bus card to integrate with an external network (MODBUS® and PROFIBUS DP are currently available).*

Additional relays and analog inputs and outputs can be added by networking a second Probe Module or optional DIN-rail communication modules.

The Hach Model sc1000 Multi-parameter Universal Controller is a state-of-the-art modular controller system. Use it directly with 8 sensors or network several together to accommodate many more sensors and parameters. It is completely compatible with Hach's full range of digital sensors.

DW
WW
PW
IW

Digital Reliability and Integration

Digital signals between the sc1000 controller and attached sensors assure data integrity and immunity from signal interference. Digital outputs from the sc1000 make it easy to integrate the controller into an existing network. Additional advanced communication features include:

- *Ethernet port (standard)—attach a computer directly to the sc1000 controller to operate the system from the computer. Download data logs and upload software updates.*
- *GSM wireless modem (optional)—use it for fully remote operation of the sc1000 controller, including transfer of data and software updates. (FCC approval pending.)*

Expandable and Upgradeable

The sc1000 controller can adapt to your needs. Change probes without changing the controller. Probe Modules can be added or removed depending on operational needs. Fully upgradeable software ensures that this system will not be obsolete.

DW = drinking water** WW = wastewater municipal **PW = pure water / power
*IW = industrial water **E = environmental** C = collections **FB = food and beverage***

HACH®
Be Right™

Specifications*

Ambient Conditions

Operation: -20 to 55°C (-4 to 131°F);
0 to 95% relative humidity, non-condensing

Storage: -20 to 70°C (-4 to 158°F);
0 to 95% relative humidity, non-condensing

Power Requirements

100 to 230 Vac, 50/60 Hz

Power: 75 W

Optional: 24 Vdc

Display

1/4 VGA graphical backlit TFT color touch screen

Resolution: 320 x 240 pixels

Relays

Up to four SPDT, user-configurable contacts rated 100 to 230 Vac, 5 Amp resistive maximum, per probe module. Additional relays are available via digital network connection.

Outputs

Up to 12 analog 0/4-20 mA, maximum impedance 500 Ohms per probe module.

Additional analog outputs are available via digital network connection.

Optional digital communications via MODBUS® (RS-485) or PROFIBUS DP.

Inputs

Up to 12 analog 0-20 mA, maximum impedance 500 Ohms per probe module.

Additional inputs are available via digital network connection.

Control

PID, high/low phasing, setpoint, deadband, overfeed timer, off delay, and on delay

Alarms

Low alarm point, low alarm point deadband, high alarm point, high alarm point deadband, off delay, and on delay

Communication (Optional)

MODBUS® (RS-485): Advanced communications/networking with PLC or SCADA system directly from analyzer.

PROFIBUS DP

GSM cellular module (FCC approval pending.)

Ethernet service port (standard)

Memory Backup

All user settings are retained indefinitely in memory (non-volatile) (EEPROM)

Mounting Configurations

Surface, panel, and pipe (horizontal and vertical)

Enclosure

IP65; ABS (display module) and metal (probe module) enclosure with corrosion-resistant finish

Dimensions

Probe module with attached display module:
315 x 250 x 142 mm (12.4 x 9.8 x 5.6 in.)

Weight

Approximately 6.5 kg (14.3 lbs.) depending on configuration

Certifications

cTUVus to UL 61010A-1 and CSA C22.2 No. 1010.1
TUV-GS to EN 61010-1
CE per 73/23/EEC and 89/336/EEC

**Specifications subject to change without notice.*

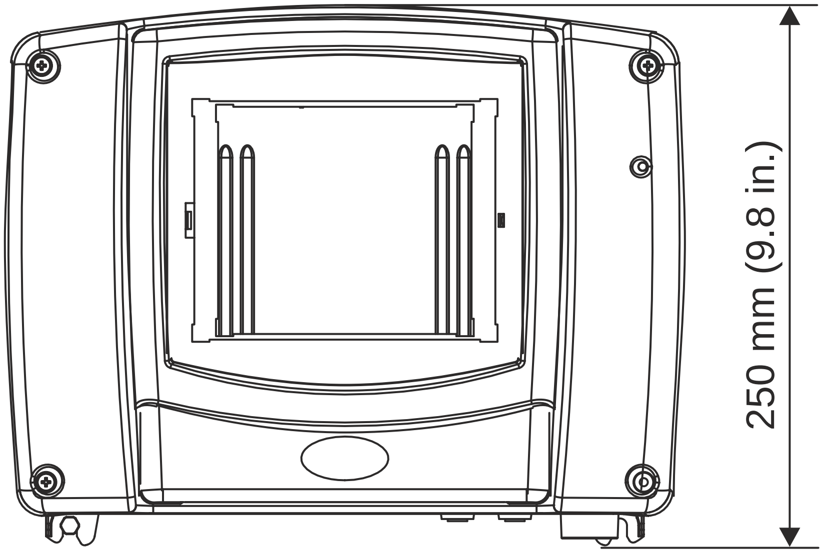
Engineering Specifications

1. The controller shall consist of a portable display module connected to one or more probe modules.
2. The portable display module shall have a color graphical touch-screen display.
3. Connections between the sensors and the controller shall be “plug and play.”
4. The controller shall have the option for MODBUS or PROFIBUS DP communication.
5. The interface unit shall allow operators to control sensor and interface functions with menu-driven software.
6. The controller shall have up to four potential free relays, four analog outputs and four analog inputs per probe module (all expandable via the controllers internal network).
7. The controller shall have an Ethernet service port for direct connection to a personal computer for transfer of data and software updates.
8. The controller shall be housed in an IP65 enclosure.
9. The controller shall be mounted horizontally or vertically on surface or pipe.
10. The AC power supply shall be housed in the interface unit and automatically accept input in the range of 100 to 230 Vac, 50/60 Hz. An internal 24 Vdc power supply shall be available as an option.
11. All system components shall be certified by cTUVus to UL 61010A-1 and CSA C22.2 No. 1010.1;
    TUV-GS to EN 61010-1;
    CE per 73/23/EEC and 89/336/EEC.
12. The controller shall be warranted for 12 months against defects in material and workmanship.
13. The controller shall be Hach Company Model sc1000 Multi-parameter Universal Controller.

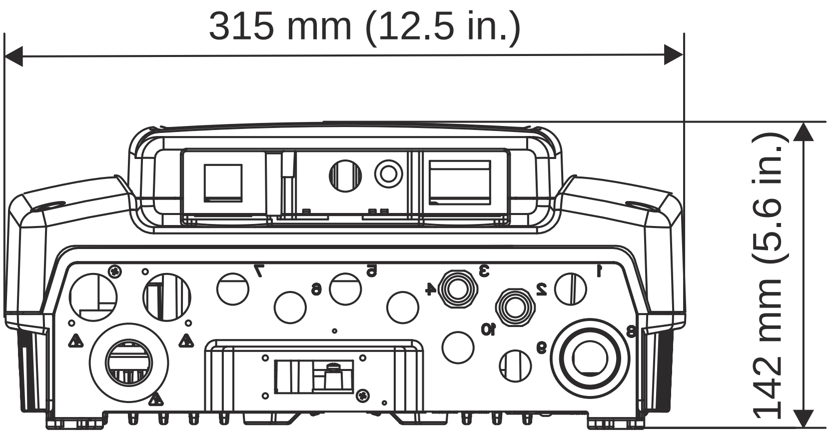
Dimensions

The sc1000 controller unit can be installed on a pole, wall, or a floor stand. No tools are needed to connect the controller unit to any Hach digital sensor.

Front View



Bottom View



Ordering Information

LXV402.99.00002	sc1000 Display Module
LXV400.99.1R572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, 110-230V
LXV400.99.1B572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, RS-485 (MODBUS), 110-230V
LXV400.99.1F572	sc1000 Probe Module, 4 sensors, 4 mA Out, 4 mA In, 4 Relays, PROFIBUS DP, 110-230V
LXV400.99.1R582	sc1000 Probe Module, 6 sensors, 4 mA Out, 4 mA In, 4 Relays, 110-230V

Additional combinations are available. Contact your Hach representative or call 1-800-227-4224 for more information.

Power Cords

54488-00	Power Cord with strain relief, 125 Vac, American-style plug
54489-00	Power Cord with strain relief, 230 Vac, European-style plug

Accessories

LZX958	Sun Shield, for sc1000 controller
LZX918	sc1000 internal network connector
LZX988	sc1000 internal network cable, 100 m (328 ft.)
LZX989	sc1000 internal network cable, 500 m (1640 ft.)

To complete your digital measurement system, choose from Hach's family of digital products...

sc100™ Controller

Plug-and-play, mix-and-match operation for one or two sensors
(see Lit. # 2463)

Hach LDO™ Dissolved Oxygen Probe

Break-through luminescent technology for dissolved oxygen
(see Lit. # 2455)

Model 5740 sc Galvanic Membrane Dissolved Oxygen Sensor

Replaceable membrane cartridge for simple maintenance
(see Lit. # 2469)

Differential pH and ORP Sensors

Three electrodes for increased measurement accuracy
(see Lit. # 2467)

3/4-inch Combination pH and ORP Sensor Kits

Designed specifically for immersion or in-line mounting
(see Lit. # 2470)

Inductive Conductivity Sensors

Innovative technology for harsh environments
(see Lit. # 2465)

Contacting Conductivity Sensors

Enhanced performance sensors for a variety of applications
(see Lit. # 2468)

1720E Low Range Turbidimeter

Meets performance criteria established by the USEPA for regulatory reporting
(see Lit. # 2457)

SOLITAX® sc Turbidity and Suspended Solids Sensors

Accurate, color-independent measurement in any application
(see Lit. # 2472)

NITRATAX™ UV Nitrate Sensors

Simple and accurate technology for low cost of operation
(see Lit. # 2464)

Lit. No. 2403
J52.5 Printed in U.S.A.

At Hach, it's about learning from our customers and providing the right answers. It's more than ensuring the quality of water—it's about ensuring the quality of life. When it comes to the things that touch our lives...

Keep it pure.

Make it simple.

Be right.

For current price information, technical support, and ordering assistance, contact the Hach office or distributor serving your area.

In the United States, contact:

HACH COMPANY World Headquarters
P.O. Box 389
Loveland, Colorado 80539-0389
U.S.A.
Telephone: 800-227-4224
Fax: 970-669-2932
E-mail: orders@hach.com
www.hach.com

U.S. exporters and customers in Canada, Latin America, sub-Saharan Africa, Asia, and Australia/New Zealand, contact:

HACH COMPANY World Headquarters
P.O. Box 389
Loveland, Colorado 80539-0389
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Telephone: 970-669-3050
Fax: 970-461-3939
E-mail: intl@hach.com
www.hach.com

In Europe, the Middle East, and Mediterranean Africa, contact:

HACH LANGE GmbH
Willstätterstraße 11
D-40549 Düsseldorf
GERMANY
Tel: +49 (0) 211 5288-0
Fax: +49 (0) 211 5288-143
E-mail: info@hach-lange.de
www.hach-lange.com

Be Right™

Appendix C

FINAL HACH PRICE QUOTE FOR PHASE 1 PURCHASE

Sales Order Acknowledgement

(This is not an Invoice)

Date: 05/08/2017

HACH COMPANY

Headquarters
P. O. Box 389
5600 Lindbergh Drive
Loveland, CO 80539-0389

Purchase Orders
PO Box 608
Loveland, CO 80539-0608
Web Site: www.hach.com

U.S.A.
Phone: 800-227-4224
Fax: 970-669-2932
Email: orders@hach.com
quotes@hach.com
bids@hach.com
techhelp@hach.com

Export
Phone: 970-669-3050
Fax: 970-461-3939
Email: intl@hach.com

Remittance
2207 Collections Center Drive
Chicago, IL 60693

Wire Transfers
Bank of America
231 S. LaSalle St.
Chicago, IL 60604
Account: 8765602385
Routing (ABA): 026009593
Swift Code: BOFAUS3N

Order Number	314603137
P.O. Number	10515A00-100
Payment Terms	Net 30
Currency	USD
Freight Terms	Prepay And Bill Customer
Ship Method	UPS-UPS**UPS --Ground
Order Date	05/03/2017
Customer Number	130767
Order Contact	BECKY LUNA
Phone	3034046313
Fax	
E-Mail	bluna@carollo.com

Bill-To	Ship-To	Deliver-To
178192 CAROLLO ENGINEERS 4600 E WASHINGTON STE 500 PHOENIX,AZ,85034 /United States	319334 CITY OF SANTA FE WASTEWATER TREATMENT PLANT 73 PASEO REAL SANTA FE,NM,87507-8482 /United States	

Ln#	Item No	Description	Order Qty	Out of Stock	Requested Date	Expected Ship Date	Unit Price	Extended Amount
1.1	9020000	ASSY, PROBE, LDO MODEL 2, HACH Unit price includes 8.00% discount	4	2	05/01/2017	05/30/2017	1,763.64	7,054.56
2.1	9253000	KTO: POLE MOUNT, 1" NPT SENSOR Unit price includes 8.00% discount	4	0	05/01/2017	05/30/2017	443.44	1,773.76
3.1	5796600	Black Metalized Mylar Bag, 6x16 to calibrate the LDO with. Unit price includes 8.00% discount	1	0	05/01/2017	05/30/2017	5.11	5.11
4.1	5796100	Digital Extension Cable, 15m (50 ft) Unit price includes 8.00% discount	2	0	05/01/2017	05/30/2017	249.32	498.64
5.1	5796200	Digital Extension Cable, 31m (100ft) Unit price includes 8.00% discount	2	0	05/01/2017	05/30/2017	331.20	662.40
6.1	LXV417.99.20002	db NITRATAX PLUS SC 2MM Unit price includes 8.00% discount	2	0	05/01/2017	05/30/2017	16,159.80	32,319.60
7.1	LZY714.99.52220	POLE MOUNTING HARDWARE NITRAT, 24CM BRACKET, SS PO Unit price includes 8.00% discount	2	2	05/01/2017	05/30/2017	510.60	1,021.20
8.1	LCW828	CONTROL STANDARD 25 MG/L NO3 Unit price includes 8.00% discount	1	0	05/01/2017	05/30/2017	55.06	55.06
9.1	5796100	Digital Extension Cable, 15m (50 ft) Unit price includes 8.00% discount	1	0	05/01/2017	05/30/2017	249.32	249.32

Sales Order Acknowledgement

(This is not an Invoice)

Date: 05/08/2017

Ln#	Item No	Description	Order Qty	Out of Stock	Requested Date	Expected Ship Date	Unit Price	Extended Amount
10.1	5796200	Digital Extension Cable, 31m (100ft) Unit price includes 8.00% discount	3	0	05/01/2017	05/30/2017	331.20	993.60
11.1	MTC10105	aa ORP GEL-FILLED PROBE, RUG w/5m CABLE Unit price includes 8.00% discount	1	0	05/01/2017	05/30/2017	554.76	554.76
12.1	2316949	ORP STD SOLN, ZOBELL'S, 500ML Unit price includes 8.00% discount	1	0	05/01/2017	05/30/2017	48.90	48.90
13.1	2756549	Solution to store your pH electrodes comes in a 500 mL bottle. Unit price includes 8.00% discount	1	0	05/01/2017	05/30/2017	32.25	32.25
14.1	LXV400.99.1U382	ee SC1000 PM 6 SENS 2X4-20MA OUT PROGNSYS RELAY HACH Unit price includes 8.00% discount	2	2	05/01/2017	05/30/2017	2,880.52	5,761.04
15.1	LXV402.99.10002	aa db ee sc1000 DISPLAY MODULE, TCP, NO GSM Unit price includes 8.00% discount	2	0	05/01/2017	05/30/2017	3,284.40	6,568.80
16.1	LZX958	SUNSHIELD, SC1000 Unit price includes 8.00% discount	2	0	05/01/2017	05/30/2017	149.96	299.92

Merchandise Total:	$57,898.92
Shipping & Handling:	$1,085.74
Tax:	$2,967.33
Total :	$61,951.99

NOTES :

Out of stock quantities exist on your order. You will receive an e-mail confirmation at the time of shipment. We apologize for any inconvenience this delay may have caused. To make order changes, you may respond to this e-mail, or contact Customer Service

Additional charges may be added for certain heavy/large items shipping to US Destinations. Some states require tax to be applied to freight charges. The freight tax will be added at time of invoice.

Your Order Total is $25,000 or more, please send a confirming purchase order to address or fax number above.

All purchases of Hach Company products and/or services are expressly and without limitation subject to Hach Company's Terms & Conditions of Sale ("Hach TCS"), incorporated herein by reference and published on Hach Company's website at www.hach.com/terms. Hach TCS are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale "Contract" in accordance with the Hach TCS: (i) Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of the Hach TCS are not part of the Contract.

Due to International regulations, a U.S. Department of Commerce Export License may be required. Hach reserves the right to approve specific shipping agents. Wooden boxes suitable for ocean shipment are extra. Specify final destination to ensure proper documentation and packing suitable for International transport. In addition, Hach may require: 1). A statement of intended end-use; 2). Certification that the intended end-use does not relate to proliferation of weapons of mass destruction (prohibited nuclear end-use, chemical /biological weapons, missile technology); and 3). Certification that the goods will not be diverted contrary to U.S. law.

IN LIEU OF PAYMENT TERMS, HACH RESERVES THE RIGHT TO REQUIRE CASH OR CREDIT CARD PAYMENT IN ADVANCE OF DELIVERY. SALES/USE TAXES ARE INCLUDED IN YOUR ACKNOWLEDGEMENT OF ORDER. Taxes will be added for orders shipping and used in US Destinations, unless valid resale/exemption certificate is provided. Exemption certificate can be sent to the above address or fax number.

Hach Hydromet	Hach Flow Products & Services	Environmental Test Systems (ETS)	Other Hach Brands
800-949-3766	800-368-2723	800-548-4381	800-454-0263
Fax: 970-461-3921	Fax: 970-619-5150	Fax: 970-619-5025	Fax: 970-461-3919

Appendix D

BACKUP HACH PRICE QUOTES

Quotation

Hach
PO Box 608
Loveland, CO 80539-0608
Phone: (800) 227-4224
Email: quotes@hach.com
Website: www.hach.com

Quote Number: 100244049v1

Use quote number at time of order to ensure that you receive prices quoted

Quote Date: 07-Apr-2017

Quote Expiration: 06-Jun-2017

CITY OF SANTA FE
WASTEWATER TREATMENT PLANT
73 PASEO REAL
SANTA FE, NM 87507-8482

Name: Luis Orozco
Phone: 505-955-4615
Email: lgorozco@santafenm.gov

Customer Account Number : 178051

Sales Contact: Cory Taylor Email: ctaylor@hach.com Phone: 800-227-4224

PRICING QUOTATION

Line	Part Number	Description	Qty	Unit Price	Extended Price
.					
1	LXV440.99.10002	AISE sc w RFID (USA) w Cartridge Low cost ISE Ammonium probe (immersion), 10m cable	1	7,428.00	7,428.00
2	LZY694	ee SENSOR CARTRIDGE INCL. SHIPPING BOOT, POLISHING STRIPS, AN-ISE sc / A-ISE sc / N-ISE sc	1	989.00	989.00
3	LZY706	CLEANING UNIT AN-ISEsc,A-ISEsc,N-ISEsc	1	289.00	289.00
4	6860000	CLEAN SYS,HI OUTPUT AIR BL HACH 115V	1	1,927.00	1,927.00
5	FSPAISE	Field Service includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 2 on-site calibrations per year, factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	1	3,103.00	3,103.00
				Grand Total	$ 13,736.00

TERMS OF SALE

Freight: Ground Prepay and Add

FOB: Origin

All purchases of Hach Company products and/or services are expressly and without limitation subject to Hach Company's Terms & Conditions of Sale ("Hach TCS"), incorporated herein by reference and published on Hach Company's website at www.hach.com/terms. Hach TCS are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale "Contract" in accordance with the Hach TCS: (i) Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of the Hach TCS are not part of the Contract.

Due to International regulations, a U.S. Department of Commerce Export License may be required. Hach reserves the right to approve specific shipping agents. Wooden boxes suitable for ocean shipment are extra. Specify final destination to ensure proper documentation and packing suitable for International transport. In addition, Hach may require : 1). A statement of intended end-use; 2).Certification that the intended end-use does not relate to proliferation of weapons of mass destruction (prohibited nuclear end use, chemical / biological weapons, missile technology); and 3). Certification that the goods will not be diverted contrary to U.S. law.

ORDER TERMS:

Terms are Subject to Credit Review
Please reference the quotation number on your purchase order.
Sales tax is not included. Applicable sales tax will be added to the invoice based on the U.S. destination, if applicable provide a resale/exemption certificate.
Shipments will be prepaid and added to invoices unless otherwise specified.
Equipment quoted operates with standard U.S. supply voltage.
Hach standard terms and conditions apply to all sales.
Additional terms and conditions apply to orders for service partnerships.
Prices do not include delivery of product. Reference attached Freight Charge Schedule and Collect Handling Fees.
Standard lead time is 30 days.
This Quote is good for a one time purchase.

Sales Contact:		Prepared By:	
Name:	Cory Taylor	Name:	Carol Burrill
Title:	Regional Sales Manager	Title:	Field Sales Support Specialist II
Phone:	800-227-4224	Phone:	970-669-3050 x6246
Email:	ctaylor@hach.com	Email:	cburrill@hach.com

HACH COMPANY

Headquarters
P.O. Box 389
5600 Lindbergh Drive
Loveland, CO 80539-0389

Purchase Orders
PO Box 608
Loveland, CO 80539-0608

WebSite: www.hach.com

U.S.A.
Phone: 800-227-4224
Fax: 970-669-2932
E-Mail: orders@hach.com
quotes@hach.com
techhelp@hach.com

Export
Phone: 970-669-3050
Fax: 970-461-3939
Email: intl@hach.com

Remittance
2207 Collections Center Drive
Chicago, IL 60693

Wire Transfers
Bank of America
231 S. LaSalle St.
Chicago, IL 60604
Account: 8765602385
Routing (ABA): 071000039

Quotation Addendum

ADVANTAGES OF WORKING WITH HACH

Technical Support

Provides post-sale instrumentation and application support

- ✓ Hach's highly skilled Technical Support staff is dedicated to helping you resolve technical issues before, during and after the sale.
- ✓ Available via phone, e-mail, or live online chat at Hach.com!
- ✓ Toll-free phone: 800-227-4224
- ✓ E-mail: techhelp@hach.com

www.Hach.com

SIRR Delivery Program

The Scheduled Inventory Reagent Replacement (SIRR) Program offers an uninterrupted supply of reagents

- ✓ Lower inventory costs and fresh supplies
- ✓ Reduced paperwork – one purchase order for the entire year
- ✓ Automatic shipments on your schedule
- ✓ Easier budgeting

www.Hach.com/sirr

Hach WarrantyPlus™ Upgrade

Instrument Protection and Service

- ✓ Savings of more than 20% versus a "pay as you go" approach
- ✓ Freedom from maintenance
- ✓ Worry-free compliance with Hach's certification
- ✓ Fixed maintenance budget for the entire year

www.Hach.com/warrantyplus

ADVANTAGES OF SIMPLIFIED SHIPPING AND HANDLING

Safe & Fast Delivery

- ✓ Receive tracking numbers on your order acknowledgement
- ✓ Hach will assist with claims if an order is lost or damaged in shipment

Save Time – Less Hassle

- ✓ No need to set up deliveries for orders or to schedule pickup
- ✓ Hach ships order as product is available, at no additional charge, when simplified shipping and handling is used.

Save Money

- ✓ No additional invoice to process – save on time and administrative costs
- ✓ Only pay shipping once, even if multiple shipments are required

STANDARD SIMPLIFIED SHIPPING AND HANDLING CHARGES [1, 2, 3]				*Pricing Effective 10/3/2016*		**Collect [4]**
Total Price of Merchandise Ordered	Standard Surface (Mainland USA)	Second Day Delivery (Mainland USA)	Next Day Delivery (Mainland USA)	Second Day Delivery (Alaska & Hawaii)	Next Day Delivery (Alaska & Hawaii)	Handling Fee *Effective 10/3/2016*
$0.00 - $49.99	$11.99	$29.99	$54.99	$44.95	$85.45	$7.98
$50.00 - $149.99	$17.79	$52.45	$98.97	$71.64	$136.19	$8.21
$150.00 - $349.99	$30.89	$79.43	$161.79	$100.23	$195.06	$8.72
$350.00 - $649.99	$41.67	$108.95	$216.68	$136.20	$263.73	$9.18
$650.00 - $949.99	$52.77	$114.40	$239.39	$141.65	$267.00	$9.50
$950.00 - $1,999.99	$66.39	$141.16	$298.48	$167.98	$325.04	$10.37
$2,000.00 - $3,999.99	$76.27	$151.01	$305.84	$173.67	$330.31	$11.99
$4,000.00 - $5,999.99	$88.42	$155.77	$320.61	$174.47	$339.85	$14.76
$6,000.00 - $7,999.99	$104.48	$176.56	$355.05	$192.45	$371.02	$17.22
$8,000.00 - $9,999.99	$119.79	$201.60	$393.94	$215.71	$409.10	$19.87
Over $10,000	2% of Net Order Value	4% of Net Order Value	6% of Net Order Value	4% of Net Order Value	6% of Net Order Value	$30.43

[1] Shipping & Handling charges shown are only applicable to orders billing and shipping to U.S. destinations. Shipping & Handling charges will be prepaid and added to invoice. Shipping & Handling for the Reagent Delivery Program is charged on each shipment release and is based on the total price of each shipment release. Shipping & Handling charges are subject to change without notice.

[2] Additional Shipping & Handling charges will be applied to orders containing bulky and/or especially heavy orders. Refrigerated and all weather Samplers do not qualify for simplified Shipping & Handling charges, and are considered heavy products. Dissolved Oxygen Sensors can be damaged if exposed to temps below freezing, causing sensor failure. Must be shipped over night or 2nd day air during the cold weather months.

[3] Orders shipping to Alaska or Hawaii: Additional Shipping & Handling charges may be applied at time of order processing. Second Day and Next Day delivery is not available to all destinations.

[4] Hach Company will assess a collect handling fee on orders with collect shipping terms. This handling fee covers the additional costs that Hach Company incurs from processing and managing collect shipments.

SALES TAX

Sales Tax is not included in the attached quotation. Applicable sales and usage taxes will be added to your invoice, at the time of order, based on U.S. destination of goods, unless a valid resale/exemption certificate for destination state is provided to the above address or fax number, attention of the Tax Dept.

TERMS & CONDITIONS OF SALE FOR HACH COMPANY PRODUCTS AND SERVICES

This document sets forth the Terms & Conditions of Sale for goods manufactured and/or supplied, and services provided, by Hach Company of Loveland, Colorado ("Hach") and sold to the original purchaser thereof ("Buyer"). Unless otherwise specifically stated herein, the term "Hach" includes only Hach Company and none of its affiliates. Unless otherwise specifically stated in a previously-executed written purchase agreement signed by authorized representatives of Hach and Buyer, these Terms & Conditions of Sale establish the rights, obligations and remedies of Hach and Buyer which apply to this offer and any resulting order or contract for the sale of Hach's goods and/or services ("Products").

1. APPLICABLE TERMS & CONDITIONS: These Terms & Conditions of Sale are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale ("Contract") in accordance with these Terms & Conditions: (i) Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of these Terms & Conditions of Sale are not a part of the Contract.

2. CANCELLATION: Buyer may cancel goods orders subject to fair charges for Hach's expenses including handling, inspection, restocking, freight and invoicing charges as applicable, provided that Buyer returns such goods to Hach at Buyer's expense within 30 days of delivery and in the same condition as received. Buyer may cancel service orders on ninety (90) day's prior written notice and refunds will be prorated based on the duration of the service plan. Inspections and re-instatement fees may apply upon cancellation or expiration of service programs. Seller may cancel all or part of any order prior to delivery without liability if the order includes any Products that Seller determines may not comply with export, safety, local certification, or other applicable compliance requirements.

3. DELIVERY: Delivery will be accomplished FCA Hach's facility located in Ames, Iowa or Loveland, Colorado, United States (Incoterms 2010). For orders having a final destination within the U.S., legal title and risk of loss or damage pass to Buyer upon transfer to the first carrier. For orders having a final destination outside the U.S., legal title and risk of loss or damage pass to Buyer when the Products enter international waters or airspace or cross an international frontier. Hach will use commercially reasonable efforts to deliver the Products ordered herein within the time specified on the face of this Contract or, if no time is specified, within Hach's normal lead-time necessary for Hach to deliver the Products sold hereunder. Upon prior agreement with Buyer and for an additional charge, Hach will deliver the Products on an expedited basis. Standard service delivery hours are 8 am – 5 pm Monday through Friday, excluding holidays.

4. INSPECTION: Buyer will promptly inspect and accept any Products delivered pursuant to this Contract after receipt of such Products. In the event the Products do not conform to any applicable specifications, Buyer will promptly notify Hach of such nonconformance in writing. Hach will have a reasonable opportunity to repair or replace the nonconforming product at its option. Buyer will be deemed to have accepted any Products delivered hereunder and to have waived any such nonconformance in the event such a written notification is not received by Hach within thirty (30) days of delivery.

5. PRICES & ORDER SIZES: All prices are in U.S. dollars and are based on delivery as stated above. Prices do not include any charges for services such as insurance; brokerage fees; sales, use, inventory or excise taxes; import or export duties; special financing fees; VAT, income or royalty taxes imposed outside the U.S.; consular fees; special permits or licenses; or other charges imposed upon the production, sale, distribution, or delivery of Products. Buyer will either pay any and all such charges or provide Hach with acceptable exemption certificates, which obligation survives performance under this Contract. Hach reserves the right to establish minimum order sizes and will advise Buyer accordingly.

6. PAYMENTS: All payments must be made in U.S. dollars. For Internet orders, the purchase price is due at the time and manner set forth at www.hach.com. Invoices for all other orders are due and payable NET 30 DAYS from date of the invoice without regard to delays for inspection or transportation, with payments to be made by check to Hach at the above address or by wire transfer to the account stated on the front of Hach's invoice, or for customers with no established credit, Hach may require cash or credit card payment in advance of delivery. In the event payments are not made or not made in a timely manner, Hach may, in addition to all other remedies provided at law, either: (a) declare Buyer's performance in breach and terminate this Contract for default; (b) withhold future shipments until delinquent payments are made; (c) deliver future shipments on a cash-with-order or cash-in-advance basis even after the delinquency is cured; (d) charge interest on the delinquency at a rate of 1-1/2% per month or the maximum rate permitted by law, if lower, for each month or part thereof of delinquency in payment plus applicable storage charges and/or inventory carrying charges; (e) repossess the Products for which payment has not been made; (f) recover all costs of collection including reasonable attorney's fees; or (g) combine any of the above rights and remedies as is practicable and permitted by law. Buyer is prohibited from setting off any and all monies owed under this from any other sums, whether liquidated or not, that are or may be due Buyer, which arise out of a different transaction with Hach or any of its affiliates. Should Buyer's financial responsibility become unsatisfactory to Hach in its reasonable discretion, Hach may require cash payment or other security. If Buyer fails to meet these requirements, Hach may treat such failure as reasonable grounds for repudiation of this Contract, in which case reasonable cancellation charges shall be due Hach. Buyer grants Hach a security interest in the Products to secure payment in full, which payment releases the security interest but only if such payments could not be considered an avoidable transfer under the U.S. Bankruptcy Code or other applicable laws. Buyer's insolvency, bankruptcy, assignment for the benefit of creditors, or dissolution or termination of the existence of Buyer, constitutes a default under this Contract and affords Hach all the remedies of a secured party under the U.C.C., as well as the remedies stated above for late payment or non-payment. See ¶22 for further wire transfer requirements.

7. LIMITED WARRANTY: Hach warrants that Products sold hereunder will be free from defects in material and workmanship and will, when used in accordance with the manufacturer's operating and maintenance instructions, conform to any express written warranty pertaining to the specific goods purchased, which for most Hach instruments is for a period of twelve (12) months from delivery. Hach warrants that services furnished hereunder will be free from defects in workmanship for a period of ninety (90) days from the completion of the services. Parts provided by Hach in the performance of services may be new or refurbished parts functioning equivalent to new parts. Any non-functioning parts that are repaired by Hach shall become the property of Hach. No warranties are extended to consumable items such as, without limitation, reagents, batteries, mercury cells, and light bulbs. **All other guarantees, warranties, conditions and representations, either express or implied, whether arising under any statute, law, commercial usage or otherwise, including implied warranties of merchantability and fitness for a particular purpose, are hereby excluded.** The sole remedy for Products not meeting this Limited Warranty is replacement, credit or refund of the purchase price. This remedy will not be deemed to have failed of its essential purpose so long as Hach is willing to provide such replacement, credit or refund.

8. INDEMNIFICATION: Indemnification applies to a party and to such party's successors-in-interest, assignees, affiliates, directors, officers, and employees ("Indemnified Parties"). Hach is responsible for and will defend, indemnify and hold harmless the Buyer Indemnified Parties against all losses, claims, expenses or damages which may result from accident, injury, damage, or death due to Hach's breach of the Limited Warranty. This indemnification is provided on the condition that the Buyer is likewise responsible for and will defend, indemnify and hold harmless the Hach Indemnified Parties against all losses, claims, expenses or damages which may result from accident, injury, damage, or death due to the negligence or misuse or misapplication of any goods or services by the Buyer or any third party affiliated or in privity with Buyer.

9. PATENT PROTECTION: Subject to all limitations of liability provided herein, Hach will, with respect to any Products of Hach's design or manufacture, indemnify Buyer from any and all damages and costs as finally determined by a court of competent jurisdiction in any suit for infringement of any U.S. patent (or European patent for Products that Hach sells to Buyer for end use in a member state of the E.U.) that has issued as of the delivery date, solely by reason of the sale or normal use of any Products sold to Buyer hereunder and from reasonable expenses incurred by Buyer in defense of such suit if Hach does not undertake the defense thereof, provided that Buyer promptly notifies Hach of such suit and offers Hach either (i) full and exclusive control of the defense of such suit when Products of Hach only are involved, or (ii) the right to participate in the defense of such suit when products other than those of Hach are also involved. Hach's warranty as to use patents only applies to infringement arising solely out of the inherent operation of the Products according to their applications as envisioned by Hach's specifications. In case the Products are in such suit held to constitute infringement and the use of the Products is enjoined, Hach will, at its own expense and at its option, either procure for Buyer the right to continue using such Products or replace them with non-infringing products, or modify them so they become non-infringing, or remove the Products and refund the purchase price (prorated for depreciation) and the transportation costs thereof. The foregoing states the entire liability of Hach for patent infringement by the Products. Further, to the same extent as set forth in Hach's above obligation to Buyer, Buyer agrees to defend, indemnify and hold harmless Hach for patent infringement related to (x) any goods manufactured to the Buyer's design, (y) services provided in accordance with the Buyer's instructions, or (z) Hach's Products when used in combination with any other devices, parts or software not provided by Hach hereunder.

10. TRADEMARKS AND OTHER LABELS: Buyer agrees not to remove or alter any indicia of manufacturing origin or patent numbers contained on or within the Products, including without limitation the serial numbers or trademarks on nameplates or cast, molded or machined components.

11. SOFTWARE. All licenses to Hach's separately-provided software products are subject to the separate software license agreement(s) accompanying the software media. In the absence of such terms and for all other software, Hach grants Buyer only a personal, non-exclusive license to access and use the software provided by Hach with Products purchased hereunder solely as necessary for Buyer to enjoy the benefit of the Products. A portion of the software may contain or consist of open source software, which Buyer may use under the terms and conditions of the specific license under which the open source software is distributed. Buyer agrees that it will be bound by any and all such license agreements. Title to software remains with the applicable licensor(s).

12. PROPRIETARY INFORMATION; PRIVACY: "Proprietary Information" means any information, technical data or know-how in whatever form, whether documented, contained in machine readable or physical components, mask works or artwork, or otherwise, which Hach considers proprietary, including but not limited to service and maintenance manuals. Buyer and its customers, employees and agents will keep confidential all such Proprietary Information obtained directly or indirectly from Hach and will not transfer or disclose it without Hach's prior written consent, or use it for the manufacture, procurement, servicing or calibration of Products or any similar products, or cause such products to be manufactured, serviced or calibrated by or procured from any other source, or reproduce or otherwise appropriate it. All such Proprietary Information remains Hach's property. No right or license is granted to Buyer or its customers, employees or agents, expressly or by implication, with respect to the Proprietary Information or any patent right or other proprietary right of Hach, except for the limited use licenses implied by law. Hach will manage Customer's information and personal data in accordance with its Privacy Policy, located at http://www.hach.com/privacypolicy.

13. CHANGES AND ADDITIONAL CHARGES: Hach reserves the right to make design changes or improvements to any products of the same general class as Products being delivered hereunder without liability or obligation to incorporate such changes or improvements to Products ordered by Buyer unless agreed upon in writing before the Products' delivery date. Services which must be performed as a result of any of the following conditions are subject to additional charges for labor, travel and parts: (a) equipment alterations not authorized in writing by Hach; (b) damage resulting from improper use or handling, accident, neglect, power surge, or operation in an environment or manner in which the instrument is not designed to operate or is not in accordance with Hach's operating manuals; (c) the use of parts or accessories not provided by Hach; (d) damage resulting from acts of war, terrorism or nature; (e) services outside standard business hours; (f) site prework not complete per proposal; or (g) any repairs required to ensure equipment meets manufacturer's specifications upon activation of a service agreement.

14. SITE ACCESS / PREPARATION / WORKER SAFETY / ENVIRONMENTAL COMPLIANCE: In connection with services provided by Hach, Buyer agrees to permit prompt access to equipment. Buyer assumes full responsibility to back-up or otherwise protect its data against loss, damage or destruction before services are performed. Buyer is the operator and in full control of its premises, including those areas where Hach employees or contractors are performing service, repair and maintenance activities. Buyer will ensure that all necessary measures are taken for safety and security of working conditions, sites and installations during the performance of services. Buyer is the generator of any resulting wastes, including without limitation hazardous wastes. Buyer is solely responsible to arrange for the disposal of any wastes at its own expense. Buyer will, at its own expense, provide Hach employees and contractors working on Buyer's premises with all information and training required under applicable safety compliance regulations and Buyer's policies. If the instrument to be serviced is in a Confined Space, as that term is defined under OSHA regulations, Buyer is solely responsible to make it available to be serviced in an unconfined space. Hach service technicians will not work in Confined Spaces. In the event that a Buyer requires Hach employees or contractors to attend safety or compliance training programs provided by Buyer, Buyer will pay Hach the standard hourly rate and expense reimbursement for such training attended. The attendance at or completion of such training does not create or expand any warranty or obligation of Hach and does not serve to alter, amend, limit or supersede any part of this Contract.

15. LIMITATIONS ON USE: Buyer will not use any Products for any purpose other than those identified in Hach's catalogs and literature as intended uses. Unless Hach has advised the Buyer in writing, in no event will Buyer use any Products in drugs, food additives, food or cosmetics, or medical applications for humans or animals. In no event will Buyer use in any application any Product that requires FDA 510(k) clearance unless and only to the extent the Product has such clearance. Any warranty granted by Hach is void if any goods covered by such warranty are used for any purpose not permitted hereunder.

16. EXPORT AND IMPORT LICENSES AND COMPLIANCE WITH LAWS: Unless otherwise specified in this Contract, Buyer is responsible for obtaining any required export or import licenses. Hach represents that all Products delivered hereunder will be produced and supplied in compliance with all applicable laws and regulations. Buyer will comply with all laws and regulations applicable to the installation or use of all Products, including applicable import and export control laws and regulations of the U.S., E.U. and any other country having proper jurisdiction, and will obtain all necessary export licenses in connection with any subsequent export, re-export, transfer and use of all Products and technology delivered hereunder. Buyer will not sell, transfer, export or re-export any Hach Products or technology for use in activities which involve the design, development, production, use or stockpiling of nuclear, chemical or biological weapons or missiles, nor use Hach Products or technology in any facility which engages in activities relating to such weapons. Buyer will comply with all local, national, and other laws of all jurisdictions globally relating to anti-corruption, bribery, extortion, kickbacks, or similar matters which are applicable to Buyer's business activities in connection with this Contract, including but not limited to the U.S. Foreign Corrupt Practices Act of 1977, as amended (the "FCPA"). Buyer agrees that no payment of money or provision of anything of value will be offered, promised, paid or transferred, directly or indirectly, by any person or entity, to any government official, government employee, or employee of any company owned in part by a government, political party, political party official, or candidate for any government office or political party office to induce such organizations or persons to use their authority or influence to obtain or retain an improper business advantage for Buyer or for Hach, or which otherwise constitute or have the purpose or effect of public or commercial bribery, acceptance of or acquiescence in extortion, kickbacks or other unlawful or improper means of obtaining business or any improper advantage, with respect to any of Buyer's activities related to this Contract. Hach asks Buyer to "*Speak Up*!" if aware of any violation of law, regulation or our Standards of Conduct ("SOC") in relation to this Contract. See http://danaher.com/integrity-and-compliance and www.danaherintegrity.com for a copy of the SOC and for access to our Helpline portal.

17. FORCE MAJEURE: Hach is excused from performance of its obligations under this Contract to the extent caused by acts or omissions that are beyond its control of, including but not limited to Government embargoes, blockages, seizures or freeze of assets, delays or refusals to grant an export or import license or the suspension or revocation thereof, or any other acts of any Government; fires, floods, severe weather conditions, or any other acts of God; quarantines; labor strikes or lockouts; riots; strife; insurrections; civil disobedience or acts of criminals or terrorists; war; material shortages or delays in deliveries to Hach by third parties. In the event of the existence of any force majeure circumstances, the period of time for delivery, payment terms and payments under any letters of credit will be extended for a period of time equal to the period of delay. If the force majeure circumstances extend for six months, Hach may, at its option, terminate this Contract without penalty and without being deemed in default or in breach thereof.

18. NON ASSIGNMENT AND WAIVER: Buyer will not transfer or assign this Contract or any rights or interests hereunder without Hach's prior written consent. Failure of either party to insist upon strict performance of any provision of this Contract, or to exercise any right or privilege contained herein, or the waiver of any breach of the terms or conditions of this Contract will not be construed as thereafter waiving any such terms, conditions, rights, or privileges, and the same will continue and remain in force and effect as if no waiver had occurred.

19. LIMITATION OF LIABILITY: None of the Hach Indemnified Parties will be liable to Buyer under any circumstances for any special, treble, incidental or consequential damages, including without limitation, damage to or loss of property other than for the Products purchased hereunder; damages incurred in installation, repair or replacement; lost profits, revenue or opportunity; loss of use; losses resulting from or related to downtime of the products or inaccurate measurements or reporting; the cost of substitute products; or claims of Buyer's customers for such damages, howsoever caused, and whether based on warranty, contract, and/or tort (including negligence, strict liability or otherwise). The total liability of the Hach Indemnified Parties arising out of the performance or nonperformance hereunder or Hach's obligations in connection with the design, manufacture, sale, delivery, and/or use of Products will in no circumstance exceed in the aggregate a sum equal to twice the amount actually paid to Hach for Products delivered hereunder.

20. APPLICABLE LAW AND DISPUTE RESOLUTION: The construction, interpretation and performance hereof and all transactions hereunder shall be governed by the laws of the State of Colorado, without regard to its principles or laws regarding conflicts of laws. If any provision of this Contract violates any Federal, State or local statutes or regulations of any countries having jurisdiction of this transaction, or is illegal for any reason, said provision shall be self-deleting without affecting the validity of the remaining provisions. Unless otherwise specifically agreed upon in writing between Hach and Buyer, any dispute relating to this Contract which is not resolved by the parties shall be adjudicated in order of preference by a court of competent jurisdiction (i) in the State of Colorado, U.S.A. if Buyer has minimum contacts with Colorado and the U.S., (ii) elsewhere in the U.S. if Buyer has minimum contacts with the U.S. but not Colorado, or (iii) in a neutral location if Buyer does not have minimum contacts with the United States.

21. ENTIRE AGREEMENT & MODIFICATION: These Terms & Conditions of Sale constitute the entire agreement between the parties and supersede any prior agreements or representations, whether oral or written. No change to or modification of these Terms & Conditions shall be binding upon Hach unless in a written instrument specifically referencing that it is amending these Terms & Conditions of Sale and signed by an authorized representative of Hach. Hach rejects any additional or inconsistent Terms & Conditions of Sale offered by Buyer at any time, whether or not such terms or conditions materially alter the Terms & Conditions herein and irrespective of Hach's acceptance of Buyer's order for the described goods and services.

* * *

Additional Provisions

22. WIRE TRANSFERS: Buyer and Hach both recognize that there is a risk of wire fraud when individuals impersonating a business demand immediate payment under new wire transfer instructions. To avoid this risk, Buyer must verbally confirm any new or changed wire transfer instructions by calling Hach at +1-970-663-1377 and speaking with Hach's Credit Manager before transferring any monies using the new wire instructions. Both parties agree that they will not institute wire transfer instruction changes and require immediate payment under the new instructions but will instead provide a ten (10) day grace period to verify any wire transfer instruction changes before any outstanding payments are due using the new instructions.

* * *

v. 2015-06-03

Quotation

Hach
PO Box 608
Loveland, CO 80539-0608
Phone: (800) 227-4224
Email: quotes@hach.com
Website: www.hach.com

Quote Number: 100243986v4
Use quote number at time of order to ensure
that you receive prices quoted

Quote Date: 07-Apr-2017 Quote Expiration: 06-Jun-2017

CITY OF SANTA FE
WASTEWATER TREATMENT PLANT
73 PASEO REAL
SANTA FE, NM 87507-8482

Name: Luis Orozco
Phone: 505-955-4615
Email: lgorozco@santafenm.gov

Customer Account Number : 178051

Sales Contact: Cory Taylor Email: ctaylor@hach.com Phone: 800-227-4224

PRICING QUOTATION

Line	Part Number	Description	Qty	Unit Price	Extended Price
Dissolved Oxygen					
1	9020000	ASSY, PROBE, LDO MODEL 2, HACH	4	1,917.00	7,668.00
2	9253000	KTO: POLE MOUNT, 1" NPT SENSOR	4	482.00	1,928.00
3	5796600	Black Metalized Mylar Bag, 6x16 to calibrate the LDO with.	1	5.55	5.55
4	5796000	Digital Extension Cable, 7.7m (25ft)	2	182.00	364.00
5	5796100	Digital Extension Cable, 15m (50 ft)	2	271.00	542.00
Nitrate					
6	LXV417.99.20002	db NITRATAX PLUS SC 2MM	2	17,565.00	35,130.00
7	LZY714.99.52220	Pole mounting hardware Nitrat, 24cm bracket, SS pole 2m	2	555.00	1,110.00
8	LCW828	CONTROL STANDARD 25 MG/L NO3	1	59.85	59.85
9	5796200	Digital Extension Cable, 31m (100ft)	3	360.00	1,080.00
10	5796100	Digital Extension Cable, 15m (50 ft)	1	271.00	271.00
Process ORP					
11	DRD1P5	pHD sc, Differential ORP Digital Sensor, PEEK Body Material, Convertible Body Style, Platinum Electrode, 70 C (158 F) Maximum Temperature	1	1,086.00	1,086.00
12	MH236B00Z	pHD Immersion Mounting Hardware, handrail hardware, CPVC	1	468.00	468.00
13	25M1A1025-115	Standard Cell Solution for pHD sc and pHD, packaged in resealable 500 ml bottle	1	70.19	70.19
14	SB-P1SV	Salt Bridge for pHD sc and pHD, PEEK Body and Kynar (PVDF) Outer Junction for PEEK Sensor	1	78.19	78.19
15	25M2A1001-115	200 mV, ORP reference solution, 500 ml (1 pint)	1	61.55	61.55
16	5796000	Digital Extension Cable, 7.7m (25ft)	1	182.00	182.00
Grap Sample HQ40-ORP Option					
17	MTC10105	aa ORP GEL-FILLED PROBE, RUG w/5m CABLE	1	603.00	603.00
18	2316949	ORP STD SOLN, ZOBELL'S, 500ML	1	53.15	53.15
19	2756549	Solution to store your pH electrodescomes in a 500 mL bottle.	1	35.05	35.05
Controllers					
20	LXV400.99.1U382	SC1000 PM 6 SENS 2X4-20MA OUT PROGNSYS RELAY HACH	2	3,131.00	6,262.00

Line	Part Number	Description	Qty	Unit Price	Extended Price
21	LXV402.99.00002	db MODULE, DISPLAY W/O GSM, SC1000	2	2,826.00	5,652.00
22	LZX958	SUNSHIELD, SC1000	2	163.00	326.00
				Grand Total	$ 63,035.53

RECOMMENDED ACCESSORIES & SERVICES

Line	Part Number	Description	Qty	Unit Price	Extended Price
1	WRTUPGLDO2	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 1 on-site visit for cleaning, inspection, air calibration, and factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	4	472.00	1,888.00
2	WRTUPGNITRATAX	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 2 on-site calibrations per year, factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	2	1,078.00	2,156.00
3	WRTUPGGLPHORP	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 1 on-site calibration per year, factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	1	237.00	237.00
4	WRTUPGSC1000	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 1 on-site factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	2	250.00	500.00
				Subtotal	$ 4,781.00

TERMS OF SALE

Freight: Ground Prepay and Add

FOB: Origin

All purchases of Hach Company products and/or services are expressly and without limitation subject to Hach Company's Terms & Conditions of Sale ("Hach TCS"), incorporated herein by reference and published on Hach Company's website at www.hach.com/terms. Hach TCS are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale "Contract" in accordance with the Hach TCS: (i) Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of the Hach TCS are not part of the Contract.

Due to International regulations, a U.S. Department of Commerce Export License may be required. Hach reserves the right to approve specific shipping agents. Wooden boxes suitable for ocean shipment are extra. Specify final destination to ensure proper documentation and packing suitable for International transport. In addition, Hach may require : 1). A statement of intended end-use; 2).Certification that the intended end-use does not relate to proliferation of weapons of mass destruction (prohibited nuclear end use, chemical / biological weapons, missile technology); and 3). Certification that the goods will not be diverted contrary to U.S. law.

ORDER TERMS:
Terms are Subject to Credit Review
Please reference the quotation number on your purchase order.
Sales tax is not included. Applicable sales tax will be added to the invoice based on the U.S. destination, if applicable provide a resale/exemption certificate.
Shipments will be prepaid and added to invoices unless otherwise specified.
Equipment quoted operates with standard U.S. supply voltage.
Hach standard terms and conditions apply to all sales.
Additional terms and conditions apply to orders for service partnerships.
Prices do not include delivery of product. Reference attached Freight Charge Schedule and Collect Handling Fees.
Standard lead time is 30 days.
This Quote is good for a one time purchase.

Sales Contact:
Name: Cory Taylor
Title: Regional Sales Manager
Phone: 800-227-4224
Email: ctaylor@hach.com

Prepared By:
Name: Carol Burrill
Title: Field Sales Support Specialist II
Phone: 970-669-3050 x6246
Email: cburrill@hach.com

HACH COMPANY

Headquarters
P.O. Box 389
5600 Lindbergh Drive
Loveland, CO 80539-0389

Purchase Orders
PO Box 608
Loveland, CO 80539-0608

WebSite: www.hach.com

U.S.A.
Phone: 800-227-4224
Fax: 970-669-2932
E-Mail: orders@hach.com
quotes@hach.com
techhelp@hach.com

Export
Phone: 970-669-3050
Fax: 970-461-3939
Email: intl@hach.com

Remittance
2207 Collections Center Drive
Chicago, IL 60693

Wire Transfers
Bank of America
231 S. LaSalle St.
Chicago, IL 60604
Account: 8765602385
Routing (ABA): 071000039

Quotation Addendum

ADVANTAGES OF WORKING WITH HACH

Technical Support

Provides post-sale instrumentation and application support

- ✓ Hach's highly skilled Technical Support staff is dedicated to helping you resolve technical issues before, during and after the sale.
- ✓ Available via phone, e-mail, or live online chat at Hach.com!
- ✓ Toll-free phone: 800-227-4224
- ✓ E-mail: techhelp@hach.com

www.Hach.com

SIRR Delivery Program

The Scheduled Inventory Reagent Replacement (SIRR) Program offers an uninterrupted supply of reagents

- ✓ Lower inventory costs and fresh supplies
- ✓ Reduced paperwork – one purchase order for the entire year
- ✓ Automatic shipments on your schedule
- ✓ Easier budgeting

www.Hach.com/sirr

Hach WarrantyPlus™ Upgrade

Instrument Protection and Service

- ✓ Savings of more than 20% versus a "pay as you go" approach
- ✓ Freedom from maintenance
- ✓ Worry-free compliance with Hach's certification
- ✓ Fixed maintenance budget for the entire year

www.Hach.com/warrantyplus

ADVANTAGES OF SIMPLIFIED SHIPPING AND HANDLING

Safe & Fast Delivery

- ✓ Receive tracking numbers on your order acknowledgement
- ✓ Hach will assist with claims if an order is lost or damaged in shipment

Save Time – Less Hassle

- ✓ No need to set up deliveries for orders or to schedule pickup
- ✓ Hach ships order as product is available, at no additional charge, when simplified shipping and handling is used.

Save Money

- ✓ No additional invoice to process – save on time and administrative costs
- ✓ Only pay shipping once, even if multiple shipments are required

STANDARD SIMPLIFIED SHIPPING AND HANDLING CHARGES [1, 2, 3] *Pricing Effective 10/3/2016*

Total Price of Merchandise Ordered	Standard Surface (Mainland USA)	Second Day Delivery (Mainland USA)	Next Day Delivery (Mainland USA)	Second Day Delivery (Alaska & Hawaii)	Next Day Delivery (Alaska & Hawaii)	**Collect [4]** Handling Fee *Effective 10/3/2016*
$0.00 - $49.99	$11.99	$29.99	$54.99	$44.95	$85.45	$7.98
$50.00 - $149.99	$17.79	$52.45	$98.97	$71.64	$136.19	$8.21
$150.00 - $349.99	$30.89	$79.43	$161.79	$100.23	$195.06	$8.72
$350.00 - $649.99	$41.67	$108.95	$216.68	$136.20	$263.73	$9.18
$650.00 - $949.99	$52.77	$114.40	$239.39	$141.65	$267.00	$9.50
$950.00 - $1,999.99	$66.39	$141.16	$298.48	$167.98	$325.04	$10.37
$2,000.00 - $3,999.99	$76.27	$151.01	$305.84	$173.67	$330.31	$11.99
$4,000.00 - $5,999.99	$88.42	$155.77	$320.61	$174.47	$339.85	$14.76
$6,000.00 - $7,999.99	$104.48	$176.56	$355.05	$192.45	$371.02	$17.22
$8,000.00 - $9,999.99	$119.79	$201.60	$393.94	$215.71	$409.10	$19.87
Over $10,000	2% of Net Order Value	4% of Net Order Value	6% of Net Order Value	4% of Net Order Value	6% of Net Order Value	$30.43

[1] Shipping & Handling charges shown are only applicable to orders billing and shipping to U.S. destinations. Shipping & Handling charges will be prepaid and added to invoice. Shipping & Handling for the Reagent Delivery Program is charged on each shipment release and is based on the total price of each shipment release. Shipping & Handling charges are subject to change without notice.

[2] Additional Shipping & Handling charges will be applied to orders containing bulky and/or especially heavy orders. Refrigerated and all weather Samplers do not qualify for simplified Shipping & Handling charges, and are considered heavy products. Dissolved Oxygen Sensors can be damaged if exposed to temps below freezing, causing sensor failure. Must be shipped over night or 2nd day air during the cold weather months.

[3] Orders shipping to Alaska or Hawaii: Additional Shipping & Handling charges may be applied at time of order processing. Second Day and Next Day delivery is not available to all destinations.

[4] Hach Company will assess a collect handling fee on orders with collect shipping terms. This handling fee covers the additional costs that Hach Company incurs from processing and managing collect shipments.

SALES TAX

Sales Tax is not included in the attached quotation. Applicable sales and usage taxes will be added to your invoice, at the time of order, based on U.S. destination of goods, unless a valid resale/exemption certificate for destination state is provided to the above address or fax number, attention of the Tax Dept.

TERMS & CONDITIONS OF SALE FOR HACH COMPANY PRODUCTS AND SERVICES

This document sets forth the Terms & Conditions of Sale for goods manufactured and/or supplied, and services provided, by Hach Company of Loveland, Colorado ("Hach") and sold to the original purchaser thereof ("Buyer"). Unless otherwise specifically stated herein, the term "Hach" includes only Hach Company and none of its affiliates. Unless otherwise specifically stated in a previously-executed written purchase agreement signed by authorized representatives of Hach and Buyer, these Terms & Conditions of Sale establish the rights, obligations and remedies of Hach and Buyer which apply to this offer and any resulting order or contract for the sale of Hach's goods and/or services ("Products").

1. APPLICABLE TERMS & CONDITIONS: These Terms & Conditions of Sale are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale ("Contract") in accordance with these Terms & Conditions: (i) Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of these Terms & Conditions of Sale are not a part of the Contract.

2. CANCELLATION: Buyer may cancel goods orders subject to fair charges for Hach's expenses including handling, inspection, restocking, freight and invoicing charges as applicable, provided that Buyer returns such goods to Hach at Buyer's expense within 30 days of delivery and in the same condition as received. Buyer may cancel service orders on ninety (90) day's prior written notice and refunds will be prorated based on the duration of the service plan. Inspections and re-instatement fees may apply upon cancellation or expiration of service programs. Seller may cancel all or part of any order prior to delivery without liability if the order includes any Products that Seller determines may not comply with export, safety, local certification, or other applicable compliance requirements.

3. DELIVERY: Delivery will be accomplished FCA Hach's facility located in Ames, Iowa or Loveland, Colorado, United States (Incoterms 2010). For orders having a final destination within the U.S., legal title and risk of loss or damage pass to Buyer upon transfer to the first carrier. For orders having a final destination outside the U.S., legal title and risk of loss or damage pass to Buyer when the Products enter international waters or airspace or cross an international frontier. Hach will use commercially reasonable efforts to deliver the Products ordered herein within the time specified on the face of this Contract or, if no time is specified, within Hach's normal lead-time necessary for Hach to deliver the Products sold hereunder. Upon prior agreement with Buyer and for an additional charge, Hach will deliver the Products on an expedited basis. Standard service delivery hours are 8 am – 5 pm Monday through Friday, excluding holidays.

4. INSPECTION: Buyer will promptly inspect and accept any Products delivered pursuant to this Contract after receipt of such Products. In the event the Products do not conform to any applicable specifications, Buyer will promptly notify Hach of such nonconformance in writing. Hach will have a reasonable opportunity to repair or replace the nonconforming product at its option. Buyer will be deemed to have accepted any Products delivered hereunder and to have waived any such nonconformance in the event such a written notification is not received by Hach within thirty (30) days of delivery.

5. PRICES & ORDER SIZES: All prices are in U.S. dollars and are based on delivery as stated above. Prices do not include any charges for services such as insurance; brokerage fees; sales, use, inventory or excise taxes; import or export duties; special financing fees; VAT, income or royalty taxes imposed outside the U.S.; consular fees; special permits or licenses; or other charges imposed upon the production, sale, distribution, or delivery of Products. Buyer will either pay any and all such charges or provide Hach with acceptable exemption certificates, which obligation survives performance under this Contract. Hach reserves the right to establish minimum order sizes and will advise Buyer accordingly.

6. PAYMENTS: All payments must be made in U.S. dollars. For Internet orders, the purchase price is due at the time and manner set forth at www.hach.com. Invoices for all other orders are due and payable NET 30 DAYS from date of the invoice without regard to delays for inspection or transportation, with payments to be made by check to Hach at the above address or by wire transfer to the account stated on the front of Hach's invoice, or for customers with no established credit, Hach may require cash or credit card payment in advance of delivery. In the event payments are not made or not made in a timely manner, Hach may, in addition to all other remedies provided at law, either: (a) declare Buyer's performance in breach and terminate this Contract for default; (b) withhold future shipments until delinquent payments are made; (c) deliver future shipments on a cash-with-order or cash-in-advance basis even after the delinquency is cured; (d) charge interest on the delinquency at a rate of 1-1/2% per month or the maximum rate permitted by law, if lower, for each month or part thereof of delinquency in payment plus applicable storage charges and/or inventory carrying charges; (e) repossess the Products for which payment has not been made; (f) recover all costs of collection including reasonable attorney's fees; or (g) combine any of the above rights and remedies as is practicable and permitted by law. Buyer is prohibited from setting off any and all monies owed under this from any other sums, whether liquidated or not, that are or may be due Buyer, which arise out of a different transaction with Hach or any of its affiliates. Should Buyer's financial responsibility become unsatisfactory to Hach in its reasonable discretion, Hach may require cash payment or other security. If Buyer fails to meet these requirements, Hach may treat such failure as reasonable grounds for repudiation of this Contract, in which case reasonable cancellation charges shall be due Hach. Buyer grants Hach a security interest in the Products to secure payment in full, which payment releases the security interest but only if such payments could not be considered an avoidable transfer under the U.S. Bankruptcy Code or other applicable laws. Buyer's insolvency, bankruptcy, assignment for the benefit of creditors, or dissolution or termination of the existence of Buyer, constitutes a default under this Contract and affords Hach all the remedies of a secured party under the U.C.C., as well as the remedies stated above for late payment or non-payment. See ¶22 for further wire transfer requirements.

7. LIMITED WARRANTY: Hach warrants that Products sold hereunder will be free from defects in material and workmanship and will, when used in accordance with the manufacturer's operating and maintenance instructions, conform to any express written warranty pertaining to the specific goods purchased, which for most Hach instruments is for a period of twelve (12) months from delivery. Hach warrants that services furnished hereunder will be free from defects in workmanship for a period of ninety (90) days from the completion of the services. Parts provided by Hach in the performance of services may be new or refurbished parts functioning equivalent to new parts. Any non-functioning parts that are repaired by Hach shall become the property of Hach. No warranties are extended to consumable items such as, without limitation, reagents, batteries, mercury cells, and light bulbs. **All other guarantees, warranties, conditions and representations, either express or implied, whether arising under any statute, law, commercial usage or otherwise, including implied warranties of merchantability and fitness for a particular purpose, are hereby excluded.** The sole remedy for Products not meeting this Limited Warranty is replacement, credit or refund of the purchase price. This remedy will not be deemed to have failed of its essential purpose so long as Hach is willing to provide such replacement, credit or refund.

8. INDEMNIFICATION: Indemnification applies to a party and to such party's successors-in-interest, assignees, affiliates, directors, officers, and employees ("Indemnified Parties"). Hach is responsible for and will defend, indemnify and hold harmless the Buyer Indemnified Parties against all losses, claims, expenses or damages which may result from accident, injury, damage, or death due to Hach's breach of the Limited Warranty. This indemnification is provided on the condition that the Buyer is likewise responsible for and will defend, indemnify and hold harmless the Hach Indemnified Parties against all losses, claims, expenses or damages which may result from accident, injury, damage, or death due to the negligence or misuse or misapplication of any goods or services by the Buyer or any third party affiliated or in privity with Buyer.

9. PATENT PROTECTION: Subject to all limitations of liability provided herein, Hach will, with respect to any Products of Hach's design or manufacture, indemnify Buyer from any and all damages and costs as finally determined by a court of competent jurisdiction in any suit for infringement of any U.S. patent (or European patent for Products that Hach sells to Buyer for end use in a member state of the E.U.) that has issued as of the delivery date, solely by reason of the sale or normal use of any Products sold to Buyer hereunder and from reasonable expenses incurred by Buyer in defense of such suit if Hach does not undertake the defense thereof, provided that Buyer promptly notifies Hach of such suit and offers Hach either (i) full and exclusive control of the defense of such suit when Products of Hach only are involved, or (ii) the right to participate in the defense of such suit when products other than those of Hach are also involved. Hach's warranty as to use patents only applies to infringement arising solely out of the inherent operation of the Products according to their applications as envisioned by Hach's specifications. In case the Products are in such suit held to constitute infringement and the use of the Products is enjoined, Hach will, at its own expense and at its option, either procure for Buyer the right to continue using such Products or replace them with non-infringing products, or modify them so they become non-infringing, or remove the Products and refund the purchase price (prorated for depreciation) and the transportation costs thereof. The foregoing states the entire liability of Hach for patent infringement by the Products. Further, to the same extent as set forth in Hach's above obligation to Buyer, Buyer agrees to defend, indemnify and hold harmless Hach for patent infringement related to (x) any goods manufactured to the Buyer's design, (y) services provided in accordance with the Buyer's instructions, or (z) Hach's Products when used in combination with any other devices, parts or software not provided by Hach hereunder.

10. TRADEMARKS AND OTHER LABELS: Buyer agrees not to remove or alter any indicia of manufacturing origin or patent numbers contained on or within the Products, including without limitation the serial numbers or trademarks on nameplates or cast, molded or machined components.

11. SOFTWARE. All licenses to Hach's separately-provided software products are subject to the separate software license agreement(s) accompanying the software media. In the absence of such terms and for all other software, Hach grants Buyer only a personal, non-exclusive license to access and use the software provided by Hach with Products purchased hereunder solely as necessary for Buyer to enjoy the benefit of the Products. A portion of the software may contain or consist of open source software, which Buyer may use under the terms and conditions of the specific license under which the open source software is distributed. Buyer agrees that it will be bound by any and all such license agreements. Title to software remains with the applicable licensor(s).

12. PROPRIETARY INFORMATION; PRIVACY: "Proprietary Information" means any information, technical data or know-how in whatever form, whether documented, contained in machine readable or physical components, mask works or artwork, or otherwise, which Hach considers proprietary, including but not limited to service and maintenance manuals. Buyer and its customers, employees and agents will keep confidential all such Proprietary Information obtained directly or indirectly from Hach and will not transfer or disclose it without Hach's prior written consent, or use it for the manufacture, procurement, servicing or calibration of Products or any similar products, or cause such products to be manufactured, serviced or calibrated by or procured from any other source, or reproduce or otherwise appropriate it. All such Proprietary Information remains Hach's property. No right or license is granted to Buyer or its customers, employees or agents, expressly or by implication, with respect to the Proprietary Information or any patent right or other proprietary right of Hach, except for the limited use licenses implied by law. Hach will manage Customer's information and personal data in accordance with its Privacy Policy, located at http://www.hach.com/privacypolicy.

13. CHANGES AND ADDITIONAL CHARGES: Hach reserves the right to make design changes or improvements to any products of the same general class as Products being delivered hereunder without liability or obligation to incorporate such changes or improvements to Products ordered by Buyer unless agreed upon in writing before the Products' delivery date. Services which must be performed as a result of any of the following conditions are subject to additional charges for labor, travel and parts: (a) equipment alterations not authorized in writing by Hach; (b) damage resulting from improper use or handling, accident, neglect, power surge, or operation in an environment or manner in which the instrument is not designed to operate or is not in accordance with Hach's operating manuals; (c) the use of parts or accessories not provided by Hach; (d) damage resulting from acts of war, terrorism or nature; (e) services outside standard business hours; (f) site prework not complete per proposal; or (g) any repairs required to ensure equipment meets manufacturer's specifications upon activation of a service agreement.

14. SITE ACCESS / PREPARATION / WORKER SAFETY / ENVIRONMENTAL COMPLIANCE: In connection with services provided by Hach, Buyer agrees to permit prompt access to equipment. Buyer assumes full responsibility to back-up or otherwise protect its data against loss, damage or destruction before services are performed. Buyer is the operator and in full control of its premises, including those areas where Hach employees or contractors are performing service, repair and maintenance activities. Buyer will ensure that all necessary measures are taken for safety and security of working conditions, sites and installations during the performance of services. Buyer is the generator of any resulting wastes, including without limitation hazardous wastes. Buyer is solely responsible to arrange for the disposal of any wastes at its own expense. Buyer will, at its own expense, provide Hach employees and contractors working on Buyer's premises with all information and training required under applicable safety compliance regulations and Buyer's policies. If the instrument to be serviced is in a Confined Space, as that term is defined under OSHA regulations, Buyer is solely responsible to make it available to be serviced in an unconfined space. Hach service technicians will not work in Confined Spaces. In the event that a Buyer requires Hach employees or contractors to attend safety or compliance training programs provided by Buyer, Buyer will pay Hach the standard hourly rate and expense reimbursement for such training attended. The attendance at or completion of such training does not create or expand any warranty or obligation of Hach and does not serve to alter, amend, limit or supersede any part of this Contract.

15. LIMITATIONS ON USE: Buyer will not use any Products for any purpose other than those identified in Hach's catalogs and literature as intended uses. Unless Hach has advised the Buyer in writing, in no event will Buyer use any Products in drugs, food additives, food or cosmetics, or medical applications for humans or animals. In no event will Buyer use in any application any Product that requires FDA 510(k) clearance unless and only to the extent the Product has such clearance. Any warranty granted by Hach is void if any goods covered by such warranty are used for any purpose not permitted hereunder.

16. EXPORT AND IMPORT LICENSES AND COMPLIANCE WITH LAWS: Unless otherwise specified in this Contract, Buyer is responsible for obtaining any required export or import licenses. Hach represents that all Products delivered hereunder will be produced and supplied in compliance with all applicable laws and regulations. Buyer will comply with all laws and regulations applicable to the installation or use of all Products, including applicable import and export control laws and regulations of the U.S., E.U. and any other country having proper jurisdiction, and will obtain all necessary export licenses in connection with any subsequent export, re-export, transfer and use of all Products and technology delivered hereunder. Buyer will not sell, transfer, export or re-export any Hach Products or technology for use in activities which involve the design, development, production, use or stockpiling of nuclear, chemical or biological weapons or missiles, nor use Hach Products or technology in any facility which engages in activities relating to such weapons. Buyer will comply with all local, national, and other laws of all jurisdictions globally relating to anti-corruption, bribery, extortion, kickbacks, or similar matters which are applicable to Buyer's business activities in connection with this Contract, including but not limited to the U.S. Foreign Corrupt Practices Act of 1977, as amended (the "FCPA"). Buyer agrees that no payment of money or provision of anything of value will be offered, promised, paid or transferred, directly or indirectly, by any person or entity, to any government official, government employee, or employee of any company owned in part by a government, political party, political party official, or candidate for any government office or political party office to induce such organizations or persons to use their authority or influence to obtain or retain an improper business advantage for Buyer or for Hach, or which otherwise constitute or have the purpose or effect of public or commercial bribery, acceptance of or acquiescence in extortion, kickbacks or other unlawful or improper means of obtaining business or any improper advantage, with respect to any of Buyer's activities related to this Contract. Hach asks Buyer to "*Speak Up*!" if aware of any violation of law, regulation or our Standards of Conduct ("SOC") in relation to this Contract. See http://danaher.com/integrity-and-compliance and www.danaherintegrity.com for a copy of the SOC and for access to our Helpline portal.

17. FORCE MAJEURE: Hach is excused from performance of its obligations under this Contract to the extent caused by acts or omissions that are beyond its control of, including but not limited to Government embargoes, blockages, seizures or freeze of assets, delays or refusals to grant an export or import license or the suspension or revocation thereof, or any other acts of any Government; fires, floods, severe weather conditions, or any other acts of God; quarantines; labor strikes or lockouts; riots; strife; insurrections; civil disobedience or acts of criminals or terrorists; war; material shortages or delays in deliveries to Hach by third parties. In the event of the existence of any force majeure circumstances, the period of time for delivery, payment terms and payments under any letters of credit will be extended for a period of time equal to the period of delay. If the force majeure circumstances extend for six months, Hach may, at its option, terminate this Contract without penalty and without being deemed in default or in breach thereof.

18. NON ASSIGNMENT AND WAIVER: Buyer will not transfer or assign this Contract or any rights or interests hereunder without Hach's prior written consent. Failure of either party to insist upon strict performance of any provision of this Contract, or to exercise any right or privilege contained herein, or the waiver of any breach of the terms or conditions of this Contract will not be construed as thereafter waiving any such terms, conditions, rights, or privileges, and the same will continue and remain in force and effect as if no waiver had occurred.

19. LIMITATION OF LIABILITY: None of the Hach Indemnified Parties will be liable to Buyer under any circumstances for any special, treble, incidental or consequential damages, including without limitation, damage to or loss of property other than for the Products purchased hereunder; damages incurred in installation, repair or replacement; lost profits, revenue or opportunity; loss of use; losses resulting from or related to downtime of the products or inaccurate measurements or reporting; the cost of substitute products; or claims of Buyer's customers for such damages, howsoever caused, and whether based on warranty, contract, and/or tort (including negligence, strict liability or otherwise). The total liability of the Hach Indemnified Parties arising out of the performance or nonperformance hereunder or Hach's obligations in connection with the design, manufacture, sale, delivery, and/or use of Products will in no circumstance exceed in the aggregate a sum equal to twice the amount actually paid to Hach for Products delivered hereunder.

20. APPLICABLE LAW AND DISPUTE RESOLUTION: The construction, interpretation and performance hereof and all transactions hereunder shall be governed by the laws of the State of Colorado, without regard to its principles or laws regarding conflicts of laws. If any provision of this Contract violates any Federal, State or local statutes or regulations of any countries having jurisdiction of this transaction, or is illegal for any reason, said provision shall be self-deleting without affecting the validity of the remaining provisions. Unless otherwise specifically agreed upon in writing between Hach and Buyer, any dispute relating to this Contract which is not resolved by the parties shall be adjudicated in order of preference by a court of competent jurisdiction (i) in the State of Colorado, U.S.A. if Buyer has minimum contacts with Colorado and the U.S., (ii) elsewhere in the U.S. if Buyer has minimum contacts with the U.S. but not Colorado, or (iii) in a neutral location if Buyer does not have minimum contacts with the United States.

21. ENTIRE AGREEMENT & MODIFICATION: These Terms & Conditions of Sale constitute the entire agreement between the parties and supersede any prior agreements or representations, whether oral or written. No change to or modification of these Terms & Conditions shall be binding upon Hach unless in a written instrument specifically referencing that it is amending these Terms & Conditions of Sale and signed by an authorized representative of Hach. Hach rejects any additional or inconsistent Terms & Conditions of Sale offered by Buyer at any time, whether or not such terms or conditions materially alter the Terms & Conditions herein and irrespective of Hach's acceptance of Buyer's order for the described goods and services.

* * *

Additional Provisions

22. WIRE TRANSFERS: Buyer and Hach both recognize that there is a risk of wire fraud when individuals impersonating a business demand immediate payment under new wire transfer instructions. To avoid this risk, Buyer must verbally confirm any new or changed wire transfer instructions by calling Hach at +1-970-663-1377 and speaking with Hach's Credit Manager before transferring any monies using the new wire instructions. Both parties agree that they will not institute wire transfer instruction changes and require immediate payment under the new instructions but will instead provide a ten (10) day grace period to verify any wire transfer instruction changes before any outstanding payments are due using the new instructions.

* * *

Nitratax
WarrantyPlus™ Service Plan

Your Hach **Nitratax** WarrantyPlus service plan provides all inclusive parts and two scheduled preventative maintenance visit performed by a Hach Field Service Technician. The WarrantyPlus Partnership also includes all visits authorized by the Hach Technical Support Team and a special priority toll free number that will be included with your Partnership documentation.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

- Perform limited instrument cleaning.
- Review and evaluate user programmed parameters
- Evaluate all instrument alarm and warning conditions (internal to your Hach instrument)
- Verify instrument operating voltages
- Evaluate Hach supplied sample conditioning equipment and probe mounting devices
- Verify Sensor operation
- Calibration with nitrate standards or a sample specific calibration is performed.
- Replace wiper, wiper shaft O-rings and fittings once a year or as necessary during each visit at no additional charge.
- Verify software version and update as necessary

Repairs

- Perform required repair service including parts and labor as necessary
- Includes sending unit to the factory if unable to repair in the field at no additional charge. This instrument will go to the head of the bench repair queue.
- Abuse or Acts of God not covered.

Reporting/Certificate of Performance

- Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
- Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

- Provide basic end user training on general instrument operation and maintenance (Advance notice required from the customer.)

PD & RD (analog pH and ORP)
DPD & DRD (Digital pH and ORP)
6XXXPX Series Differential pH Sensors
Conductivity Sensor
WarrantyPlus™ Service Plan

Your Hach **pH, ORP, and Conductivity sensor** WarrantyPlus plan provides preventative maintenance performed by a Hach Field Service Technician. In addition, the Hach Technical Support Team is available to assist in troubleshooting your specific instrument. Please have your contract#, Model# & Serial# available when you call.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

≠ Perform limited instrument cleaning
≠ Review and evaluate user programmed parameters
≠ Performance testing of pH sensor with pH buffers (as applicable)
≠ Performance testing of ORP sensor with ORP Test Solution (as applicable)
≠ Performance testing of conductivity sensor with conductivity standard (as applicable)
≠ Calibration of meter/sensor combination.
≠ Replace Salt Bridge and filling solution once per year (as applicable)

Reporting/Certificate of Performance

≠ Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
≠ Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

≠ Provide basic end user training on general instrument operation and maintenance (Advance notice required from the customer.)

*Please see standard terms and conditions for limitations.

sc1000
WarrantyPlus™ Service Plan

Your Hach **sc1000** WarrantyPlus service plan provides all inclusive parts and one scheduled preventative maintenance visit performed by a Hach Field Service Technician. The WarrantyPlus Partnership also includes all visits authorized by the Hach Technical Support Team and a special priority toll free number that will be included with your Partnership documentation.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

- Perform limited instrument cleaning
- Review and evaluate user programmed parameters
- Evaluate all instrument alarm and warning conditions (internal to your Hach instrument)
- Verify instrument operating voltages
- Perform diagnostics and communication to sc1000 sensors.
- Verify network communication via installed communication card.
- Calibrate recorder outputs for each sensor installed on the sc1000
- Verify relay setup & operation if applicable
- Verify software version and update as necessary

Repairs

- Perform required repair service including parts and labor as necessary
- Includes sending unit to the factory if unable to repair in the field at no additional charge. This instrument will go to the head of the bench repair queue.
- Abuse or Acts of God not covered.

Reporting/Certificate of Performance

- Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
- Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

- Provide basic end user training on general instrument operation and maintenance (Advance notice required from the customer.)

LDO Model 2

WarrantyPlus™ Service Plan

Your Hach **LDO2** WarrantyPlus service plan provides: all inclusive parts and one scheduled preventative maintenance visit performed by a Hach Field Service Technician. The WarrantyPlus Partnership also includes all visits authorized by the Hach Technical Support Team and a special priority toll free number that will be included with your Partnership documentation.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

- Perform limited instrument cleaning.
- Review and evaluate instrument alarm and warning conditions (internal to your Hach instrument)
- Inspect for signs of damage and/or leakage
- Perform diagnostics and communication to the LDO sensor thru the sc200, sc100 or sc1000 controller
- Replace LDO sensor cap and program calibration information into sensor
- Calibrate the LDO sensor following manual instructions
- Verify software and update as necessary

Repairs

- Perform required repair service including parts and labor as necessary
- Includes sending unit to the factory if unable to repair controller in the field at no additional charge. This instrument will go to the head of the bench repair queue.
- Abuse or Acts of God not covered.

Reporting/Certificate of Performance

- Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
- Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

- Provide basic end user training on general instrument operation and maintenance (Advance notice required by the customer).

Quotation

Hach
PO Box 608
Loveland, CO 80539-0608
Phone: (800) 227-4224
Email: quotes@hach.com
Website: www.hach.com

Quote Number: 100244026v2

Use quote number at time of order to ensure
that you receive prices quoted

Quote Date: 07-Apr-2017

Quote Expiration: 06-Jun-2017

CITY OF SANTA FE
WASTEWATER TREATMENT PLANT
73 PASEO REAL
SANTA FE, NM 87507-8482

Name: Luis Orozco
Phone: 505-955-4615
Email: lgorozco@santafenm.gov

Customer Account Number : 178051
Customer Quote Reference: Mobile Sensor Management Proposal

Sales Contact: Cory Taylor Email: ctaylor@hach.com Phone: 800-227-4224

PRICING QUOTATION

Line	Part Number	Description	Qty	Unit Price	Extended Price
Dissolved Oxygen					
1	9020000	ASSY, PROBE, LDO MODEL 2, HACH	4	1,917.00	7,668.00
2	9253000	KTO: POLE MOUNT, 1" NPT SENSOR	4	482.00	1,928.00
3	5796600	Black Metalized Mylar Bag, 6x16 to calibrate the LDO with.	1	5.55	5.55
4	5796000	Digital Extension Cable, 7.7m (25ft)	2	182.00	364.00
5	5796100	Digital Extension Cable, 15m (50 ft)	2	271.00	542.00
Nitrate					
6	LXV417.99.20002	db NITRATAX PLUS SC 2MM	2	17,565.00	35,130.00
7	LZY714.99.52220	Pole mounting hardware Nitrat, 24cm bracket, SS pole 2m	2	555.00	1,110.00
8	LCW828	CONTROL STANDARD 25 MG/L NO3	1	59.85	59.85
9	5796200	Digital Extension Cable, 31m (100ft)	3	360.00	1,080.00
10	5796100	Digital Extension Cable, 15m (50 ft)	1	271.00	271.00
Process ORP					
11	DRD1P5	pHD sc, Differential ORP Digital Sensor, PEEK Body Material, Convertible Body Style, Platinum Electrode, 70 C (158 F) Maximum Temperature	1	1,086.00	1,086.00
12	MH236B00Z	pHD Immersion Mounting Hardware, handrail hardware, CPVC	1	468.00	468.00
13	25M1A1025-115	Standard Cell Solution for pHD sc and pHD, packaged in resealable 500 ml bottle	1	70.19	70.19
14	SB-P1SV	Salt Bridge for pHD sc and pHD, PEEK Body and Kynar (PVDF) Outer Junction for PEEK Sensor	1	78.19	78.19
15	25M2A1001-115	200 mV, ORP reference solution, 500 ml (1 pint)	1	61.55	61.55
16	5796000	Digital Extension Cable, 7.7m (25ft)	1	182.00	182.00
Grap Sample HQ40-ORP Option					
17	MTC10105	aa ORP GEL-FILLED PROBE, RUG w/5m CABLE	1	603.00	603.00
18	2316949	ORP STD SOLN, ZOBELL'S, 500ML	1	53.15	53.15
19	2756549	Solution to store your pH electrodescomes in a 500 mL bottle.	1	35.05	35.05
Controllers- Mobile Sensor Management					

Line	Part Number	Description	Qty	Unit Price	Extended Price
20	LXV446.99.1R3S1	SC1500; 6 SENS 8mA OUT 110V/COND 4 REL/C EXT MOD	2	2,978.00	5,956.00
21	LZY971	Modem Kit	2	490.00	980.00
22	LZY973	MSM Services Startup Fee	1	500.00	500.00
23	MOBILE SENSOR MANAGEMENT LDO2 SENSOR	MSM annual service fee includes: sensor connection to the cloud and data delivery	4	264.00	1,056.00
24	2001H	Annual subscription for nitratax sensors.	2	264.00	528.00
				Grand Total	$ 59,815.53

RECOMMENDED ACCESSORIES & SERVICES

Line	Part Number	Description	Qty	Unit Price	Extended Price
1	WRTUPGLDO2	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 1 on-site visit for cleaning, inspection, air calibration, and factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	4	472.00	1,888.00
2	WRTUPGNITRATAX	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 2 on-site calibrations per year, factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	2	1,078.00	2,156.00
3	WRTUPGGLPHORP	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 1 on-site calibration per year, factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	1	237.00	237.00
4	WRTUPGSC1000	Comprehensive warranty upgrade includes: Instrument start-up, all parts, labor, and travel for on-site repairs, 1 on-site factory recommended maintenance (including required parts), unlimited technical support calls, and free firmware updates. On-site response for "down" instrument repairs is typically 3 business days. Standard business hours are 8am-5pm M-F local time, excluding holidays. Please see service terms and conditions for additional details on our service plans, and to ensure you have an opportunity to review our environmental and safety requirements.	2	250.00	500.00
				Subtotal	$ 4,781.00

TERMS OF SALE

Freight: Ground Prepay and Add

FOB: Origin

All purchases of Hach Company products and/or services are expressly and without limitation subject to Hach Company's Terms & Conditions of Sale ("Hach TCS"), incorporated herein by reference and published on Hach Company's website at www.hach.com/terms. Hach TCS are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale "Contract" in accordance with the Hach TCS: (i)
Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of the Hach TCS are not part of the Contract.

Due to International regulations, a U.S. Department of Commerce Export License may be required. Hach reserves the right to approve specific shipping agents. Wooden boxes suitable for ocean shipment are extra. Specify final destination to ensure proper documentation and packing suitable for International transport. In addition, Hach may require : 1). A statement of intended end-use; 2).Certification that the intended end-use does not relate to proliferation of weapons of mass destruction (prohibited nuclear end use, chemical / biological weapons, missile technology); and 3). Certification that the goods will not be diverted contrary to U.S. law.

ORDER TERMS:
Terms are Subject to Credit Review
Please reference the quotation number on your purchase order.
Sales tax is not included. Applicable sales tax will be added to the invoice based on the U.S. destination, if applicable provide a resale/exemption certificate.
Shipments will be prepaid and added to invoices unless otherwise specified.

Equipment quoted operates with standard U.S. supply voltage.
Hach standard terms and conditions apply to all sales.
Additional terms and conditions apply to orders for service partnerships.
Prices do not include delivery of product. Reference attached Freight Charge Schedule and Collect Handling Fees.
Standard lead time is 30 days.
This Quote is good for a one time purchase.

Sales Contact:		Prepared By:	
Name:	Cory Taylor	Name:	Carol Burrill
Title:	Regional Sales Manager	Title:	Field Sales Support Specialist II
Phone:	800-227-4224	Phone:	970-669-3050 x6246
Email:	ctaylor@hach.com	Email:	cburrill@hach.com

HACH COMPANY

Headquarters
P.O. Box 389
5600 Lindbergh Drive
Loveland, CO 80539-0389

Purchase Orders
PO Box 608
Loveland, CO 80539-0608

WebSite: www.hach.com

U.S.A.
Phone: 800-227-4224
Fax: 970-669-2932
E-Mail: orders@hach.com
quotes@hach.com
techhelp@hach.com

Export
Phone: 970-669-3050
Fax: 970-461-3939
Email: intl@hach.com

Remittance
2207 Collections Center Drive
Chicago, IL 60693

Wire Transfers
Bank of America
231 S. LaSalle St.
Chicago, IL 60604
Account: 8765602385
Routing (ABA): 071000039

Quotation Addendum

ADVANTAGES OF WORKING WITH HACH

Technical Support

Provides post-sale instrumentation and application support

- ✓ Hach's highly skilled Technical Support staff is dedicated to helping you resolve technical issues before, during and after the sale.
- ✓ Available via phone, e-mail, or live online chat at Hach.com!
- ✓ Toll-free phone: 800-227-4224
- ✓ E-mail: techhelp@hach.com

www.Hach.com

SIRR Delivery Program

The Scheduled Inventory Reagent Replacement (SIRR) Program offers an uninterrupted supply of reagents

- ✓ Lower inventory costs and fresh supplies
- ✓ Reduced paperwork – one purchase order for the entire year
- ✓ Automatic shipments on your schedule
- ✓ Easier budgeting

www.Hach.com/sirr

Hach WarrantyPlus™ Upgrade

Instrument Protection and Service

- ✓ Savings of more than 20% versus a "pay as you go" approach
- ✓ Freedom from maintenance
- ✓ Worry-free compliance with Hach's certification
- ✓ Fixed maintenance budget for the entire year

www.Hach.com/warrantyplus

ADVANTAGES OF SIMPLIFIED SHIPPING AND HANDLING

Safe & Fast Delivery

- ✓ Receive tracking numbers on your order acknowledgement
- ✓ Hach will assist with claims if an order is lost or damaged in shipment

Save Time – Less Hassle

- ✓ No need to set up deliveries for orders or to schedule pickup
- ✓ Hach ships order as product is available, at no additional charge, when simplified shipping and handling is used.

Save Money

- ✓ No additional invoice to process – save on time and administrative costs
- ✓ Only pay shipping once, even if multiple shipments are required

STANDARD SIMPLIFIED SHIPPING AND HANDLING CHARGES [1, 2, 3] *Pricing Effective 10/3/2016*

Total Price of Merchandise Ordered	Standard Surface (Mainland USA)	Second Day Delivery (Mainland USA)	Next Day Delivery (Mainland USA)	Second Day Delivery (Alaska & Hawaii)	Next Day Delivery (Alaska & Hawaii)	**Collect** [4] Handling Fee *Effective 10/3/2016*
$0.00 - $49.99	$11.99	$29.99	$54.99	$44.95	$85.45	$7.98
$50.00 - $149.99	$17.79	$52.45	$98.97	$71.64	$136.19	$8.21
$150.00 - $349.99	$30.89	$79.43	$161.79	$100.23	$195.06	$8.72
$350.00 - $649.99	$41.67	$108.95	$216.68	$136.20	$263.73	$9.18
$650.00 - $949.99	$52.77	$114.40	$239.39	$141.65	$267.00	$9.50
$950.00 - $1,999.99	$66.39	$141.16	$298.48	$167.98	$325.04	$10.37
$2,000.00 - $3,999.99	$76.27	$151.01	$305.84	$173.67	$330.31	$11.99
$4,000.00 - $5,999.99	$88.42	$155.77	$320.61	$174.47	$339.85	$14.76
$6,000.00 - $7,999.99	$104.48	$176.56	$355.05	$192.45	$371.02	$17.22
$8,000.00 - $9,999.99	$119.79	$201.60	$393.94	$215.71	$409.10	$19.87
Over $10,000	2% of Net Order Value	4% of Net Order Value	6% of Net Order Value	4% of Net Order Value	6% of Net Order Value	$30.43

1 Shipping & Handling charges shown are only applicable to orders billing and shipping to U.S. destinations. Shipping & Handling charges will be prepaid and added to invoice. Shipping & Handling for the Reagent Delivery Program is charged on each shipment release and is based on the total price of each shipment release. Shipping & Handling charges are subject to change without notice.

2 Additional Shipping & Handling charges will be applied to orders containing bulky and/or especially heavy orders. Refrigerated and all weather Samplers do not qualify for simplified Shipping & Handling charges, and are considered heavy products. Dissolved Oxygen Sensors can be damaged if exposed to temps below freezing, causing sensor failure. Must be shipped over night or 2nd day air during the cold weather months.

3 Orders shipping to Alaska or Hawaii: Additional Shipping & Handling charges may be applied at time of order processing. Second Day and Next Day delivery is not available to all destinations.

4 Hach Company will assess a collect handling fee on orders with collect shipping terms. This handling fee covers the additional costs that Hach Company incurs from processing and managing collect shipments.

SALES TAX

Sales Tax is not included in the attached quotation. Applicable sales and usage taxes will be added to your invoice, at the time of order, based on U.S. destination of goods, unless a valid resale/exemption certificate for destination state is provided to the above address or fax number, attention of the Tax Dept.

HACH COMPANY | 5600 Lindbergh Drive | PO Box 389 | Loveland, Colorado 80539 | P 970.669.3050 | F 970.669.2932 | hach.com

TERMS & CONDITIONS OF SALE FOR HACH COMPANY PRODUCTS AND SERVICES

This document sets forth the Terms & Conditions of Sale for goods manufactured and/or supplied, and services provided, by Hach Company of Loveland, Colorado ("Hach") and sold to the original purchaser thereof ("Buyer"). Unless otherwise specifically stated herein, the term "Hach" includes only Hach Company and none of its affiliates. Unless otherwise specifically stated in a previously-executed written purchase agreement signed by authorized representatives of Hach and Buyer, these Terms & Conditions of Sale establish the rights, obligations and remedies of Hach and Buyer which apply to this offer and any resulting order or contract for the sale of Hach's goods and/or services ("Products").

1. APPLICABLE TERMS & CONDITIONS: These Terms & Conditions of Sale are contained directly and/or by reference in Hach's offer, order acknowledgment, and invoice documents. The first of the following acts constitutes an acceptance of Hach's offer and not a counteroffer and creates a contract of sale ("Contract") in accordance with these Terms & Conditions: (i) Buyer's issuance of a purchase order document against Hach's offer; (ii) acknowledgement of Buyer's order by Hach; or (iii) commencement of any performance by Hach pursuant to Buyer's order. Provisions contained in Buyer's purchase documents (including electronic commerce interfaces) that materially alter, add to or subtract from the provisions of these Terms & Conditions of Sale are not a part of the Contract.

2. CANCELLATION: Buyer may cancel goods orders subject to fair charges for Hach's expenses including handling, inspection, restocking, freight and invoicing charges as applicable, provided that Buyer returns such goods to Hach at Buyer's expense within 30 days of delivery and in the same condition as received. Buyer may cancel service orders on ninety (90) day's prior written notice and refunds will be prorated based on the duration of the service plan. Inspections and re-instatement fees may apply upon cancellation or expiration of service programs. Seller may cancel all or part of any order prior to delivery without liability if the order includes any Products that Seller determines may not comply with export, safety, local certification, or other applicable compliance requirements.

3. DELIVERY: Delivery will be accomplished FCA Hach's facility located in Ames, Iowa or Loveland, Colorado, United States (Incoterms 2010). For orders having a final destination within the U.S., legal title and risk of loss or damage pass to Buyer upon transfer to the first carrier. For orders having a final destination outside the U.S., legal title and risk of loss or damage pass to Buyer when the Products enter international waters or airspace or cross an international frontier. Hach will use commercially reasonable efforts to deliver the Products ordered herein within the time specified on the face of this Contract or, if no time is specified, within Hach's normal lead-time necessary for Hach to deliver the Products sold hereunder. Upon prior agreement with Buyer and for an additional charge, Hach will deliver the Products on an expedited basis. Standard service delivery hours are 8 am – 5 pm Monday through Friday, excluding holidays.

4. INSPECTION: Buyer will promptly inspect and accept any Products delivered pursuant to this Contract after receipt of such Products. In the event the Products do not conform to any applicable specifications, Buyer will promptly notify Hach of such nonconformance in writing. Hach will have a reasonable opportunity to repair or replace the nonconforming product at its option. Buyer will be deemed to have accepted any Products delivered hereunder and to have waived any such nonconformance in the event such a written notification is not received by Hach within thirty (30) days of delivery.

5. PRICES & ORDER SIZES: All prices are in U.S. dollars and are based on delivery as stated above. Prices do not include any charges for services such as insurance; brokerage fees; sales, use, inventory or excise taxes; import or export duties; special financing fees; VAT, income or royalty taxes imposed outside the U.S.; consular fees; special permits or licenses; or other charges imposed upon the production, sale, distribution, or delivery of Products. Buyer will either pay any and all such charges or provide Hach with acceptable exemption certificates, which obligation survives performance under this Contract. Hach reserves the right to establish minimum order sizes and will advise Buyer accordingly.

6. PAYMENTS: All payments must be made in U.S. dollars. For Internet orders, the purchase price is due at the time and manner set forth at www.hach.com. Invoices for all other orders are due and payable NET 30 DAYS from date of the invoice without regard to delays for inspection or transportation, with payments to be made by check to Hach at the above address or by wire transfer to the account stated on the front of Hach's invoice, or for customers with no established credit, Hach may require cash or credit card payment in advance of delivery. In the event payments are not made or not made in a timely manner, Hach may, in addition to all other remedies provided at law, either: (a) declare Buyer's performance in breach and terminate this Contract for default; (b) withhold future shipments until delinquent payments are made; (c) deliver future shipments on a cash-with-order or cash-in-advance basis even after the delinquency is cured; (d) charge interest on the delinquency at a rate of 1-1/2% per month or the maximum rate permitted by law, if lower, for each month or part thereof of delinquency in payment plus applicable storage charges and/or inventory carrying charges; (e) repossess the Products for which payment has not been made; (f) recover all costs of collection including reasonable attorney's fees; or (g) combine any of the above rights and remedies as is practicable and permitted by law. Buyer is prohibited from setting off any and all monies owed under this from any other sums, whether liquidated or not, that are or may be due Buyer, which arise out of a different transaction with Hach or any of its affiliates. Should Buyer's financial responsibility become unsatisfactory to Hach in its reasonable discretion, Hach may require cash payment or other security. If Buyer fails to meet these requirements, Hach may treat such failure as reasonable grounds for repudiation of this Contract, in which case reasonable cancellation charges shall be due Hach. Buyer grants Hach a security interest in the Products to secure payment in full, which payment releases the security interest but only if such payments could not be considered an avoidable transfer under the U.S. Bankruptcy Code or other applicable laws. Buyer's insolvency, bankruptcy, assignment for the benefit of creditors, or dissolution or termination of the existence of Buyer, constitutes a default under this Contract and affords Hach all the remedies of a secured party under the U.C.C., as well as the remedies stated above for late payment or non-payment. See ¶22 for further wire transfer requirements.

7. LIMITED WARRANTY: Hach warrants that Products sold hereunder will be free from defects in material and workmanship and will, when used in accordance with the manufacturer's operating and maintenance instructions, conform to any express written warranty pertaining to the specific goods purchased, which for most Hach instruments is for a period of twelve (12) months from delivery. Hach warrants that services furnished hereunder will be free from defects in workmanship for a period of ninety (90) days from the completion of the services. Parts provided by Hach in the performance of services may be new or refurbished parts functioning equivalent to new parts. Any non-functioning parts that are repaired by Hach shall become the property of Hach. No warranties are extended to consumable items such as, without limitation, reagents, batteries, mercury cells, and light bulbs. **All other guarantees, warranties, conditions and representations, either express or implied, whether arising under any statute, law, commercial usage or otherwise, including implied warranties of merchantability and fitness for a particular purpose, are hereby excluded.** The sole remedy for Products not meeting this Limited Warranty is replacement, credit or refund of the purchase price. This remedy will not be deemed to have failed of its essential purpose so long as Hach is willing to provide such replacement, credit or refund.

8. INDEMNIFICATION: Indemnification applies to a party and to such party's successors-in-interest, assignees, affiliates, directors, officers, and employees ("Indemnified Parties"). Hach is responsible for and will defend, indemnify and hold harmless the Buyer Indemnified Parties against all losses, claims, expenses or damages which may result from accident, injury, damage, or death due to Hach's breach of the Limited Warranty. This indemnification is provided on the condition that the Buyer is likewise responsible for and will defend, indemnify and hold harmless the Hach Indemnified Parties against all losses, claims, expenses or damages which may result from accident, injury, damage, or death due to the negligence or misuse or misapplication of any goods or services by the Buyer or any third party affiliated or in privity with Buyer.

9. PATENT PROTECTION: Subject to all limitations of liability provided herein, Hach will, with respect to any Products of Hach's design or manufacture, indemnify Buyer from any and all damages and costs as finally determined by a court of competent jurisdiction in any suit for infringement of any U.S. patent (or European patent for Products that Hach sells to Buyer for end use in a member state of the E.U.) that has issued as of the delivery date, solely by reason of the sale or normal use of any Products sold to Buyer hereunder and from reasonable expenses incurred by Buyer in defense of such suit if Hach does not undertake the defense thereof, provided that Buyer promptly notifies Hach of such suit and offers Hach either (i) full and exclusive control of the defense of such suit when Products of Hach only are involved, or (ii) the right to participate in the defense of such suit when products other than those of Hach are also involved. Hach's warranty as to use patents only applies to infringement arising solely out of the inherent operation of the Products according to their applications as envisioned by Hach's specifications. In case the Products are in such suit held to constitute infringement and the use of the Products is enjoined, Hach will, at its own expense and at its option, either procure for Buyer the right to continue using such Products or replace them with non-infringing products, or modify them so they become non-infringing, or remove the Products and refund the purchase price (prorated for depreciation) and the transportation costs thereof. The foregoing states the entire liability of Hach for patent infringement by the Products. Further, to the same extent as set forth in Hach's above obligation to Buyer, Buyer agrees to defend, indemnify and hold harmless Hach for patent infringement related to (x) any goods manufactured to the Buyer's design, (y) services provided in accordance with the Buyer's instructions, or (z) Hach's Products when used in combination with any other devices, parts or software not provided by Hach hereunder.

10. TRADEMARKS AND OTHER LABELS: Buyer agrees not to remove or alter any indicia of manufacturing origin or patent numbers contained on or within the Products, including without limitation the serial numbers or trademarks on nameplates or cast, molded or machined components.

11. SOFTWARE. All licenses to Hach's separately-provided software products are subject to the separate software license agreement(s) accompanying the software media. In the absence of such terms and for all other software, Hach grants Buyer only a personal, non-exclusive license to access and use the software provided by Hach with Products purchased hereunder solely as necessary for Buyer to enjoy the benefit of the Products. A portion of the software may contain or consist of open source software, which Buyer may use under the terms and conditions of the specific license under which the open source software is distributed. Buyer agrees that it will be bound by any and all such license agreements. Title to software remains with the applicable licensor(s).

12. PROPRIETARY INFORMATION; PRIVACY: "Proprietary Information" means any information, technical data or know-how in whatever form, whether documented, contained in machine readable or physical components, mask works or artwork, or otherwise, which Hach considers proprietary, including but not limited to service and maintenance manuals. Buyer and its customers, employees and agents will keep confidential all such Proprietary Information obtained directly or indirectly from Hach and will not transfer or disclose it without Hach's prior written consent, or use it for the manufacture, procurement, servicing or calibration of Products or any similar products, or cause such products to be manufactured, serviced or calibrated by or procured from any other source, or reproduce or otherwise appropriate it. All such Proprietary Information remains Hach's property. No right or license is granted to Buyer or its customers, employees or agents, expressly or by implication, with respect to the Proprietary Information or any patent right or other proprietary right of Hach, except for the limited use licenses implied by law. Hach will manage Customer's information and personal data in accordance with its Privacy Policy, located at http://www.hach.com/privacypolicy.

13. CHANGES AND ADDITIONAL CHARGES: Hach reserves the right to make design changes or improvements to any products of the same general class as Products being delivered hereunder without liability or obligation to incorporate such changes or improvements to Products ordered by Buyer unless agreed upon in writing before the Products' delivery date. Services which must be performed as a result of any of the following conditions are subject to additional charges for labor, travel and parts: (a) equipment alterations not authorized in writing by Hach; (b) damage resulting from improper use or handling, accident, neglect, power surge, or operation in an environment or manner in which the instrument is not designed to operate or is not in accordance with Hach's operating manuals; (c) the use of parts or accessories not provided by Hach; (d) damage resulting from acts of war, terrorism or nature; (e) services outside standard business hours; (f) site prework not complete per proposal; or (g) any repairs required to ensure equipment meets manufacturer's specifications upon activation of a service agreement.

14. SITE ACCESS / PREPARATION / WORKER SAFETY / ENVIRONMENTAL COMPLIANCE: In connection with services provided by Hach, Buyer agrees to permit prompt access to equipment. Buyer assumes full responsibility to back-up or otherwise protect its data against loss, damage or destruction before services are performed. Buyer is the operator and in full control of its premises, including those areas where Hach employees or contractors are performing service, repair and maintenance activities. Buyer will ensure that all necessary measures are taken for safety and security of working conditions, sites and installations during the performance of services. Buyer is the generator of any resulting wastes, including without limitation hazardous wastes. Buyer is solely responsible to arrange for the disposal of any wastes at its own expense. Buyer will, at its own expense, provide Hach employees and contractors working on Buyer's premises with all information and training required under applicable safety compliance regulations and Buyer's policies. If the instrument to be serviced is in a Confined Space, as that term is defined under OSHA regulations, Buyer is solely responsible to make it available to be serviced in an unconfined space. Hach service technicians will not work in Confined Spaces. In the event that a Buyer requires Hach employees or contractors to attend safety or compliance training programs provided by Buyer, Buyer will pay Hach the standard hourly rate and expense reimbursement for such training attended. The attendance at or completion of such training does not create or expand any warranty or obligation of Hach and does not serve to alter, amend, limit or supersede any part of this Contract.

15. LIMITATIONS ON USE: Buyer will not use any Products for any purpose other than those identified in Hach's catalogs and literature as intended uses. Unless Hach has advised the Buyer in writing, in no event will Buyer use any Products in drugs, food additives, food or cosmetics, or medical applications for humans or animals. In no event will Buyer use in any application any Product that requires FDA 510(k) clearance unless and only to the extent the Product has such clearance. Any warranty granted by Hach is void if any goods covered by such warranty are used for any purpose not permitted hereunder.

16. EXPORT AND IMPORT LICENSES AND COMPLIANCE WITH LAWS: Unless otherwise specified in this Contract, Buyer is responsible for obtaining any required export or import licenses. Hach represents that all Products delivered hereunder will be produced and supplied in compliance with all applicable laws and regulations. Buyer will comply with all laws and regulations applicable to the installation or use of all Products, including applicable import and export control laws and regulations of the U.S., E.U. and any other country having proper jurisdiction, and will obtain all necessary export licenses in connection with any subsequent export, re-export, transfer and use of all Products and technology delivered hereunder. Buyer will not sell, transfer, export or re-export any Hach Products or technology for use in activities which involve the design, development, production, use or stockpiling of nuclear, chemical or biological weapons or missiles, nor use Hach Products or technology in any facility which engages in activities relating to such weapons. Buyer will comply with all local, national, and other laws of all jurisdictions globally relating to anti-corruption, bribery, extortion, kickbacks, or similar matters which are applicable to Buyer's business activities in connection with this Contract, including but not limited to the U.S. Foreign Corrupt Practices Act of 1977, as amended (the "FCPA"). Buyer agrees that no payment of money or provision of anything of value will be offered, promised, paid or transferred, directly or indirectly, by any person or entity, to any government official, government employee, or employee of any company owned in part by a government, political party, political party official, or candidate for any government office or political party office to induce such organizations or persons to use their authority or influence to obtain or retain an improper business advantage for Buyer or for Hach, or which otherwise constitute or have the purpose or effect of public or commercial bribery, acceptance of or acquiescence in extortion, kickbacks or other unlawful or improper means of obtaining business or any improper advantage, with respect to any of Buyer's activities related to this Contract. Hach asks Buyer to "*Speak Up*!" if aware of any violation of law, regulation or our Standards of Conduct ("SOC") in relation to this Contract. See http://danaher.com/integrity-and-compliance and www.danaherintegrity.com for a copy of the SOC and for access to our Helpline portal.

17. FORCE MAJEURE: Hach is excused from performance of its obligations under this Contract to the extent caused by acts or omissions that are beyond its control of, including but not limited to Government embargoes, blockages, seizures or freeze of assets, delays or refusals to grant an export or import license or the suspension or revocation thereof, or any other acts of any Government; fires, floods, severe weather conditions, or any other acts of God; quarantines; labor strikes or lockouts; riots; strife; insurrections; civil disobedience or acts of criminals or terrorists; war; material shortages or delays in deliveries to Hach by third parties. In the event of the existence of any force majeure circumstances, the period of time for delivery, payment terms and payments under any letters of credit will be extended for a period of time equal to the period of delay. If the force majeure circumstances extend for six months, Hach may, at its option, terminate this Contract without penalty and without being deemed in default or in breach thereof.

18. NON ASSIGNMENT AND WAIVER: Buyer will not transfer or assign this Contract or any rights or interests hereunder without Hach's prior written consent. Failure of either party to insist upon strict performance of any provision of this Contract, or to exercise any right or privilege contained herein, or the waiver of any breach of the terms or conditions of this Contract will not be construed as thereafter waiving any such terms, conditions, rights, or privileges, and the same will continue and remain in force and effect as if no waiver had occurred.

19. LIMITATION OF LIABILITY: None of the Hach Indemnified Parties will be liable to Buyer under any circumstances for any special, treble, incidental or consequential damages, including without limitation, damage to or loss of property other than for the Products purchased hereunder; damages incurred in installation, repair or replacement; lost profits, revenue or opportunity; loss of use; losses resulting from or related to downtime of the products or inaccurate measurements or reporting; the cost of substitute products; or claims of Buyer's customers for such damages, howsoever caused, and whether based on warranty, contract, and/or tort (including negligence, strict liability or otherwise). The total liability of the Hach Indemnified Parties arising out of the performance or nonperformance hereunder or Hach's obligations in connection with the design, manufacture, sale, delivery, and/or use of Products will in no circumstance exceed in the aggregate a sum equal to twice the amount actually paid to Hach for Products delivered hereunder.

20. APPLICABLE LAW AND DISPUTE RESOLUTION: The construction, interpretation and performance hereof and all transactions hereunder shall be governed by the laws of the State of Colorado, without regard to its principles or laws regarding conflicts of laws. If any provision of this Contract violates any Federal, State or local statutes or regulations of any countries having jurisdiction of this transaction, or is illegal for any reason, said provision shall be self-deleting without affecting the validity of the remaining provisions. Unless otherwise specifically agreed upon in writing between Hach and Buyer, any dispute relating to this Contract which is not resolved by the parties shall be adjudicated in order of preference by a court of competent jurisdiction (i) in the State of Colorado, U.S.A. if Buyer has minimum contacts with Colorado and the U.S., (ii) elsewhere in the U.S. if Buyer has minimum contacts with the U.S. but not Colorado, or (iii) in a neutral location if Buyer does not have minimum contacts with the United States.

21. ENTIRE AGREEMENT & MODIFICATION: These Terms & Conditions of Sale constitute the entire agreement between the parties and supersede any prior agreements or representations, whether oral or written. No change to or modification of these Terms & Conditions shall be binding upon Hach unless in a written instrument specifically referencing that it is amending these Terms & Conditions of Sale and signed by an authorized representative of Hach. Hach rejects any additional or inconsistent Terms & Conditions of Sale offered by Buyer at any time, whether or not such terms or conditions materially alter the Terms & Conditions herein and irrespective of Hach's acceptance of Buyer's order for the described goods and services.

* * *

TERMS AND CONDITIONS OF SALE FOR HACH® PRODUCTS

<u>Additional Provisions</u>

22. WIRE TRANSFERS: Buyer and Hach both recognize that there is a risk of wire fraud when individuals impersonating a business demand immediate payment under new wire transfer instructions. To avoid this risk, Buyer must verbally confirm any new or changed wire transfer instructions by calling Hach at +1-970-663-1377 and speaking with Hach's Credit Manager before transferring any monies using the new wire instructions. Both parties agree that they will not institute wire transfer instruction changes and require immediate payment under the new instructions but will instead provide a ten (10) day grace period to verify any wire transfer instruction changes before any outstanding payments are due using the new instructions.

* * *

Nitratax
WarrantyPlus™ Service Plan

Your Hach **Nitratax** WarrantyPlus service plan provides all inclusive parts and two scheduled preventative maintenance visit performed by a Hach Field Service Technician. The WarrantyPlus Partnership also includes all visits authorized by the Hach Technical Support Team and a special priority toll free number that will be included with your Partnership documentation.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

- Perform limited instrument cleaning.
- Review and evaluate user programmed parameters
- Evaluate all instrument alarm and warning conditions (internal to your Hach instrument)
- Verify instrument operating voltages
- Evaluate Hach supplied sample conditioning equipment and probe mounting devices
- Verify Sensor operation
- Calibration with nitrate standards or a sample specific calibration is performed.
- Replace wiper, wiper shaft O-rings and fittings once a year or as necessary during each visit at no additional charge.
- Verify software version and update as necessary

Repairs

- Perform required repair service including parts and labor as necessary
- Includes sending unit to the factory if unable to repair in the field at no additional charge. This instrument will go to the head of the bench repair queue.
- Abuse or Acts of God not covered.

Reporting/Certificate of Performance

- Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
- Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

- Provide basic end user training on general instrument operation and maintenance (Advance notice required from the customer.)

HACH®
SERVICEPLUS®
CERTIFIED PROGRAMS

PD & RD (analog pH and ORP)
DPD & DRD (Digital pH and ORP)
6XXXPX Series Differential pH Sensors
Conductivity Sensor
WarrantyPlus™ Service Plan

Your Hach **pH, ORP, and Conductivity sensor** WarrantyPlus plan provides preventative maintenance performed by a Hach Field Service Technician. In addition, the Hach Technical Support Team is available to assist in troubleshooting your specific instrument. Please have your contract#, Model# & Serial# available when you call.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

- ≠ Perform limited instrument cleaning
- ≠ Review and evaluate user programmed parameters
- ≠ Performance testing of pH sensor with pH buffers (as applicable)
- ≠ Performance testing of ORP sensor with ORP Test Solution (as applicable)
- ≠ Performance testing of conductivity sensor with conductivity standard (as applicable)
- ≠ Calibration of meter/sensor combination.
- ≠ Replace Salt Bridge and filling solution once per year (as applicable)

Reporting/Certificate of Performance

- ≠ Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
- ≠ Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

- ≠ Provide basic end user training on general instrument operation and maintenance (Advance notice required from the customer.)

*Please see standard terms and conditions for limitations.

sc1000

WarrantyPlus™ Service Plan

Your Hach **sc1000** WarrantyPlus service plan provides all inclusive parts and one scheduled preventative maintenance visit performed by a Hach Field Service Technician. The WarrantyPlus Partnership also includes all visits authorized by the Hach Technical Support Team and a special priority toll free number that will be included with your Partnership documentation.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

- Perform limited instrument cleaning
- Review and evaluate user programmed parameters
- Evaluate all instrument alarm and warning conditions (internal to your Hach instrument)
- Verify instrument operating voltages
- Perform diagnostics and communication to sc1000 sensors.
- Verify network communication via installed communication card.
- Calibrate recorder outputs for each sensor installed on the sc1000
- Verify relay setup & operation if applicable
- Verify software version and update as necessary

Repairs

- Perform required repair service including parts and labor as necessary
- Includes sending unit to the factory if unable to repair in the field at no additional charge. This instrument will go to the head of the bench repair queue.
- Abuse or Acts of God not covered.

Reporting/Certificate of Performance

- Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
- Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

- Provide basic end user training on general instrument operation and maintenance (Advance notice required from the customer.)

LDO Model 2

WarrantyPlus™ Service Plan

Your Hach **LDO2** WarrantyPlus service plan provides: all inclusive parts and one scheduled preventative maintenance visit performed by a Hach Field Service Technician. The WarrantyPlus Partnership also includes all visits authorized by the Hach Technical Support Team and a special priority toll free number that will be included with your Partnership documentation.

During the pre-scheduled site visit, your Hach Field Service Technician will complete:

Verification of Instrument performance/Maintenance

≠ Perform limited instrument cleaning.
≠ Review and evaluate instrument alarm and warning conditions (internal to your Hach instrument)
≠ Inspect for signs of damage and/or leakage
≠ Perform diagnostics and communication to the LDO sensor thru the sc200, sc100 or sc1000 controller
≠ Replace LDO sensor cap and program calibration information into sensor
≠ Calibrate the LDO sensor following manual instructions
≠ Verify software and update as necessary

Repairs

≠ Perform required repair service including parts and labor as necessary
≠ Includes sending unit to the factory if unable to repair controller in the field at no additional charge. This instrument will go to the head of the bench repair queue.
≠ Abuse or Acts of God not covered.

Reporting/Certificate of Performance

≠ Provide Hach Field Service Report with complete documentation of service performed and measurements/readings.
≠ Issue Certificate of Instrument Performance for each instrument that successfully passes final testing.

Training

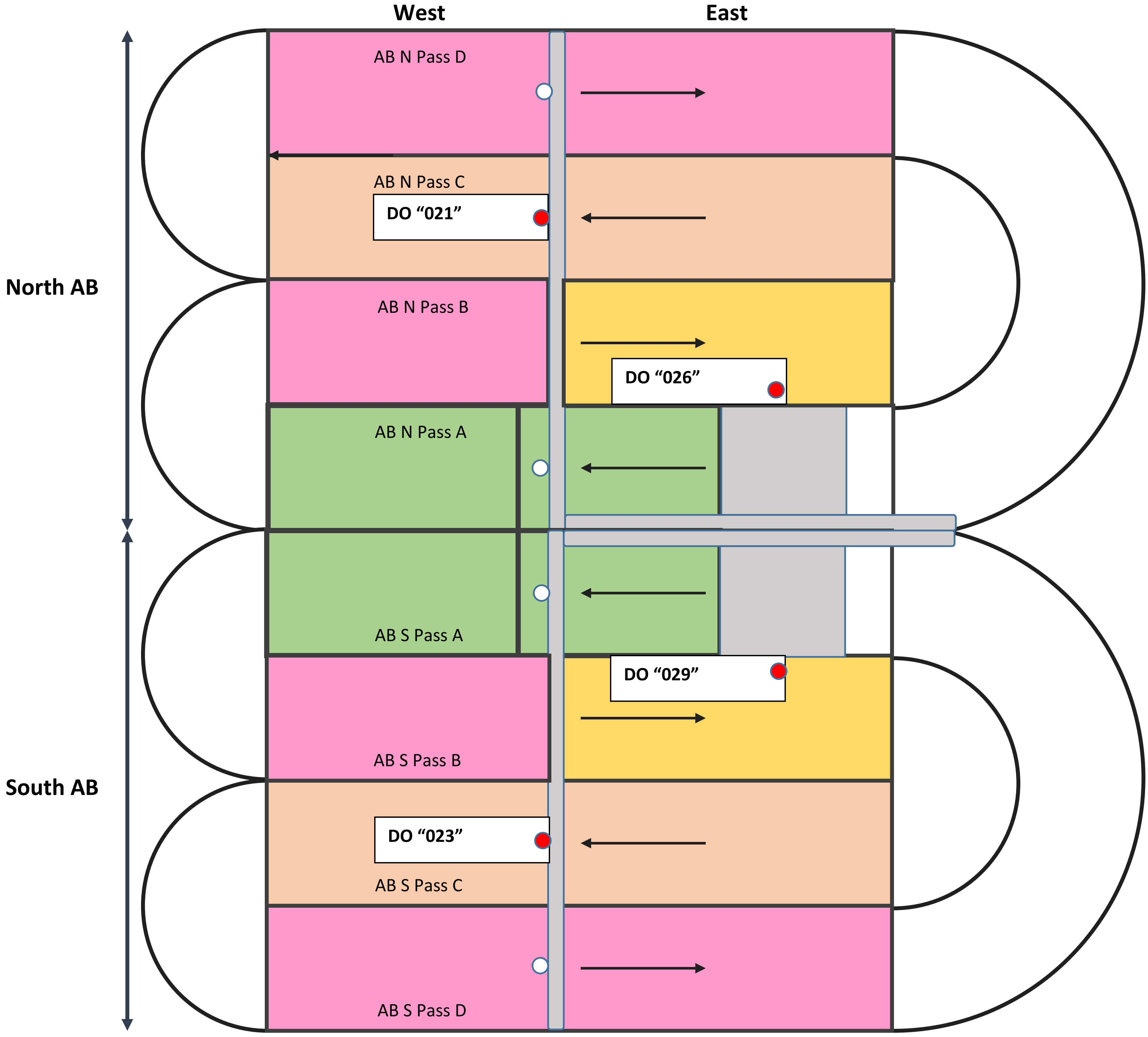
≠ Provide basic end user training on general instrument operation and maintenance (Advance notice required by the customer).

Appendix D

ALTERNATIVE AERATION PATTERNS IN AERATION BASINS

AERATION BASIN DISSOLVED OXYGEN TARGETS

December 4, 2017



🟩 AIR ON: 1.0 to 1.5 mg/L

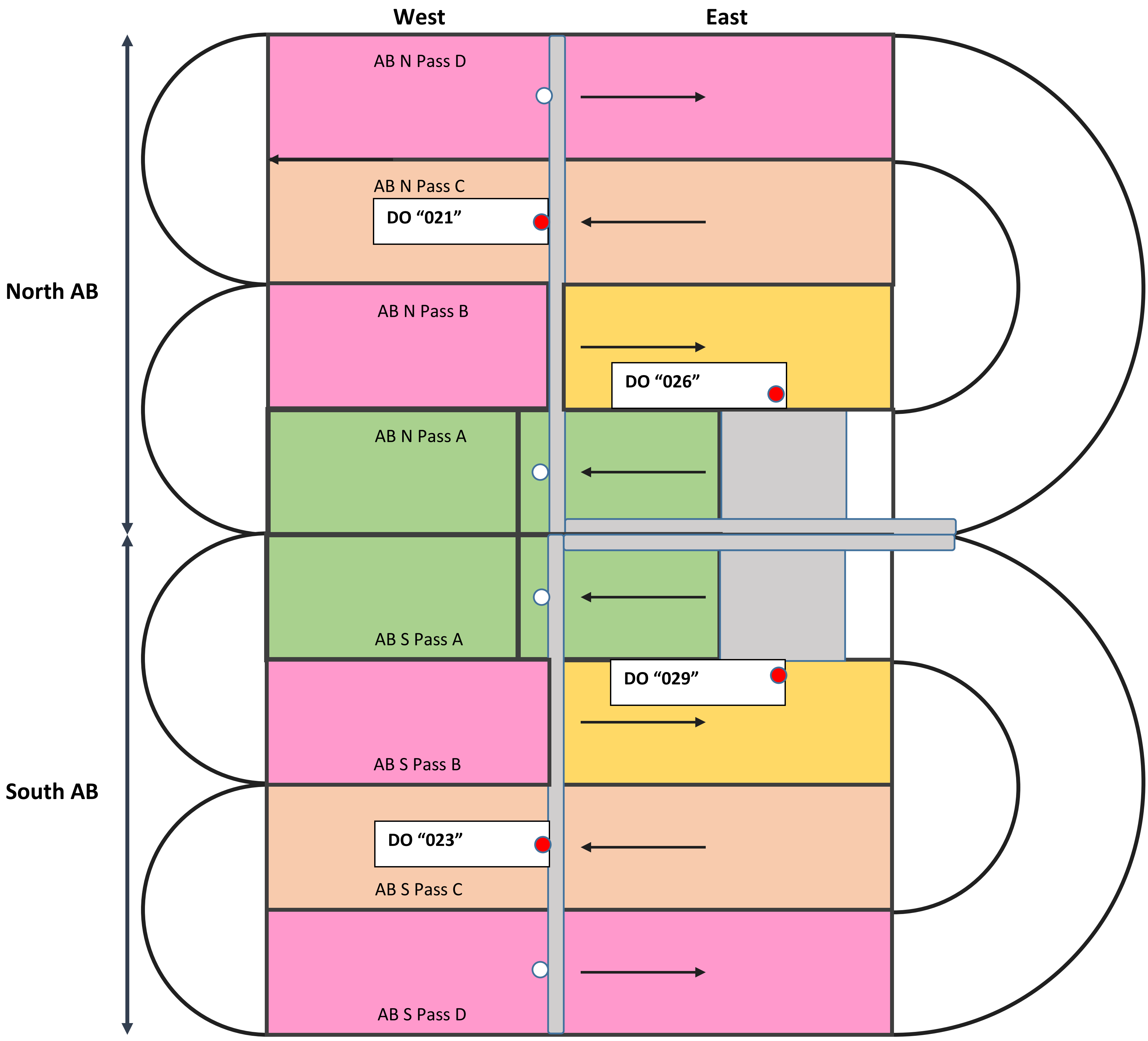
🟨 AIR ON: 0.5 to 1.0 mg/L

🟧 AIR ON: ~ 0.3 mg/L

🟪 AIR OFF

AERATION BASIN DISSOLVED OXYGEN TARGETS

December 28, 2017



🟩 **AIR ON: 1.5 mg/L**

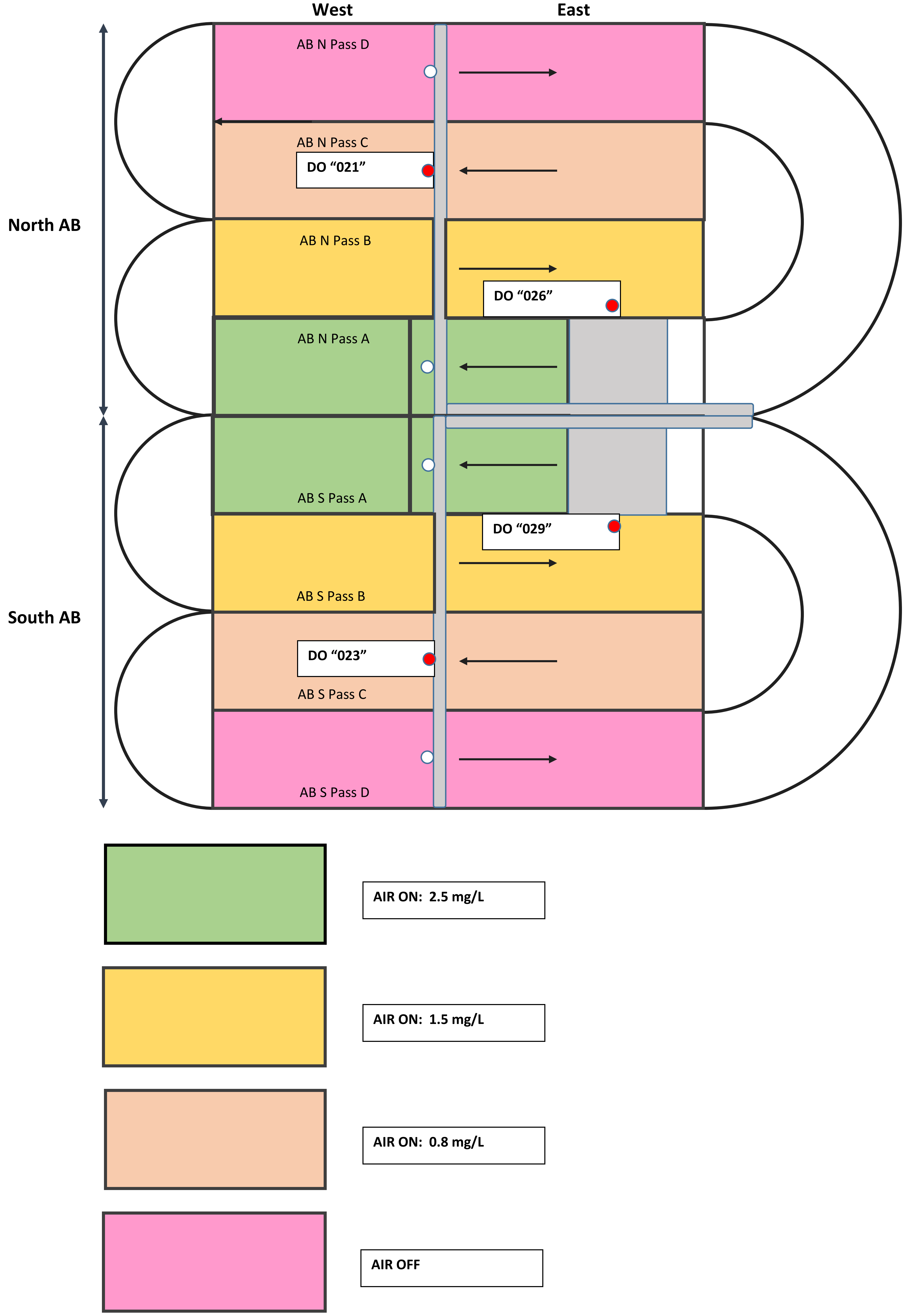
🟨 **AIR ON: 1.0 mg/L**

🟧 **AIR ON: 0.3 – 0.5 mg/L**

🟪 **AIR OFF**

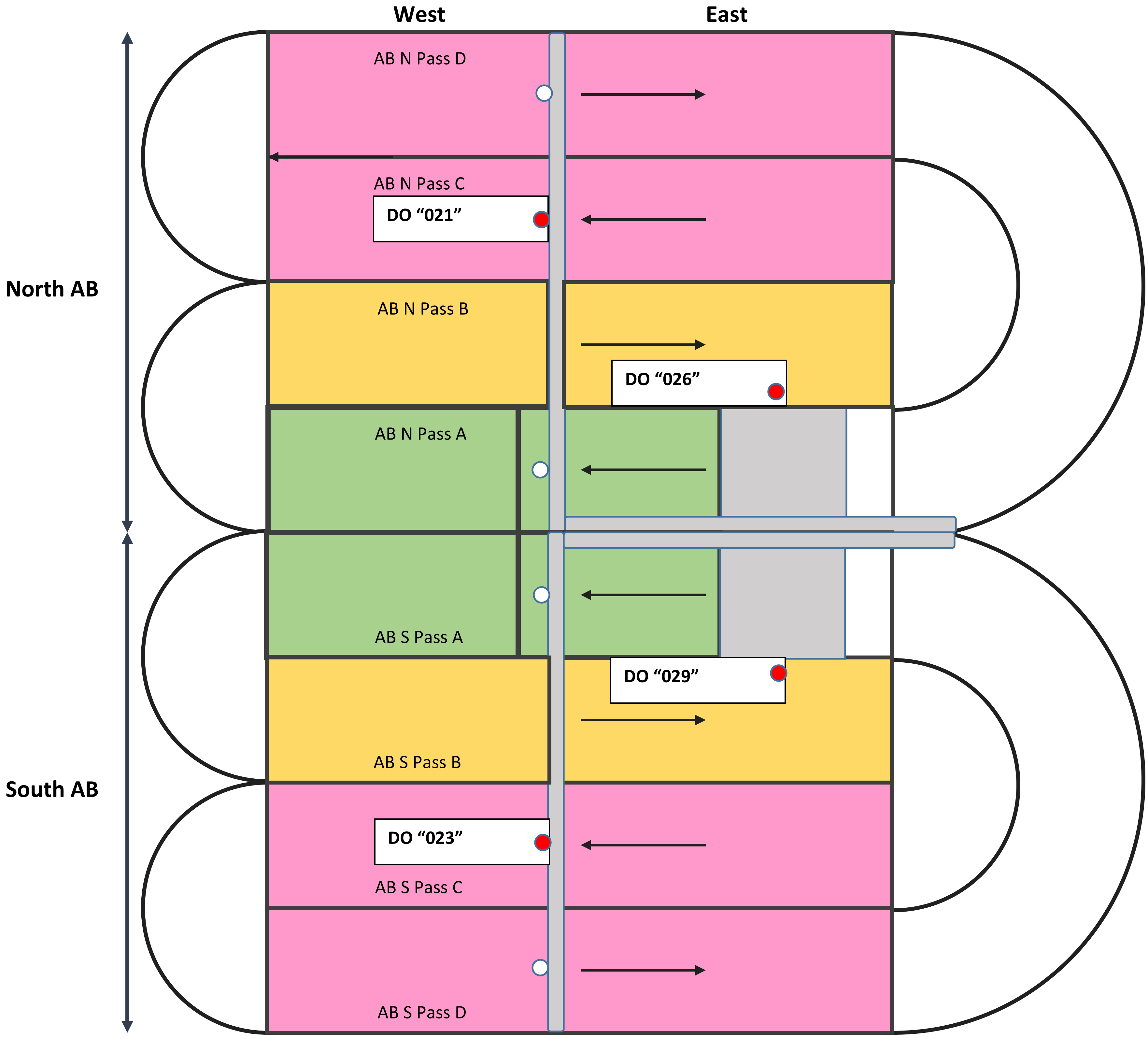
AERATION BASIN DISSOLVED OXYGEN TARGETS

January 10, 2017



AERATION BASIN DISSOLVED OXYGEN TARGETS

February 16, 2018



🟩	AIR ON: 2.0 - 2.5 mg/L
🟨	AIR ON: 1.5 mg/L
🟪	AIR OFF

Appendix E

BUDGETARY COST ESTIMATES FOR IDENTIFIED CAPITAL IMPROVEMENTS

carollo
Engineers...Working Wonders With Water®

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T1_01 Upgrades to Aeration System

Date : February-18
By : TRW
Reviewed: BJL

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	Motorized actuators (aeration droplegs)	12	EA	$ 10,000	$ 120,000
	Diffuser replacements	6385	EA	$ 4	$ 25,540
	Neuros blowers (5,500 scfm each)	3	EA	$ 125,000	$ 375,000
	Chemical pipe routing	1000	LF	$ 50	$ 50,000
	EI&C	15%	%		$ 85,581
	General Conditions	10%	%		$ 65,612
			TOTAL DIRECT COST		**$722,000**
			Contingency	30.0%	$217,000
			Subtotal		**$939,000**
			General Contractor Overhead, Profit & Risk	15.0%	$141,000
			TOTAL ESTIMATED CONSTRUCTION COST		**$1,080,000**
			Engineering, Legal & Administration Fees	15.0%	$162,000
			Owner's Reserve for Change Orders	5.0%	$54,000
			TOTAL ESTIMATED PROJECT COST		**$1,296,000**

DETAILED COST ESTIMATE

Project: **SF_Nutrient Study**
Client: **City of Santa Fe, NM**
Location: **Santa Fe, NM**
Element: **T1_02 MLR Discharge Modifications**

Date : **February-18**
By : **BJL**
Reviewed: **TRW**

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	Site Work	1	LS	$ 10,000	$ 10,000
	48" Slide gate	1	EA	$ 11,000	$ 11,000
	42" Slide gate	1	EA	$ 9,000	$ 9,000
	42" Steel Pipe	60	LF	$ 450	$ 27,000
	30" DI Pipe	60	LF	$ 435	$ 26,100
	30" BFV	2	EA	$ 11,000	$ 22,000
	Pipe Fittings	1	LS	$ 50,000	$ 50,000
	VFDs	3	EA	$ 30,000	$ 90,000
	EI&C	15%	%		$ 36,765
	General Conditions	10%	%		$ 28,187
	TOTAL DIRECT COST				**$310,000**
	Contingency			30.0%	$93,000
	Subtotal				**$403,000**
	General Contractor Overhead, Profit & Risk			15.0%	$60,000
	TOTAL ESTIMATED CONSTRUCTION COST				**$463,000**
	Engineering, Legal & Administration Fees			15.0%	$69,000
	Owner's Reserve for Change Orders			5.0%	$23,000
	TOTAL ESTIMATED PROJECT COST				**$555,000**

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T1_03 Filtrate Equalization

Date : February-18
By : TRW / MRM
Reviewed: BJL

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	Filtrate Equalization tank (incl. mixing pump and building)	1	LS	$ 717,000	$ 717,000
	Mechanical modifications	5%	%		$ 36,000
	EI&C	15%	%		$ 113,000
	General Conditions	10%	%		$ 87,000
			TOTAL DIRECT COST		**$953,000**
			Contingency	30.0%	$286,000
			Subtotal		**$1,239,000**
			General Contractor Overhead, Profit & Risk	15.0%	$186,000
			TOTAL ESTIMATED CONSTRUCTION COST		**$1,425,000**
			Engineering, Legal & Administration Fees	15.0%	$214,000
			Owner's Reserve for Change Orders	5.0%	$71,000
			TOTAL ESTIMATED PROJECT COST		**$1,710,000**

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T1_04 Side-Stream Treatment

Date : February-18
By : TRW / MRM
Reviewed: BJL

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	Filtrate Site Stream Treatment (Airprex)	1	LS	$ 2,100,000	$ 2,100,000
	Site modifications	5%	%		$ 105,000
	Mechanical modifications	10%	%		$ 221,000
	EI&C	5%	%		$ 121,000
	General Conditions	10%	%		$ 255,000
	TOTAL DIRECT COST				**$2,802,000**
	Contingency			30.0%	$841,000
	Subtotal				**$3,643,000**
	General Contractor Overhead, Profit & Risk			15.0%	$546,000
	TOTAL ESTIMATED CONSTRUCTION COST				**$4,189,000**
	Engineering, Legal & Administration Fees			15.0%	$628,000
	Owner's Reserve for Change Orders			5.0%	$209,000
	TOTAL ESTIMATED PROJECT COST				**$5,026,000**

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T2_02 Membrane Treatment

Date : February-18
By : MRM
Reviewed: BJL

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	MF Equipment Cost	1	LS		$ 12,538,000
	MF Electrical & Instrumentation	1	LS		$ 1,879,000
	MF Mechanical	1	LS		$ 1,879,000
	Modifications to existing facility (reuse existing secondary clarifier)	1	LS		$ 200,000
	General Conditions	5%			$ 824,800
	TOTAL DIRECT COST				**$17,321,000**
	Contingency			30.0%	$5,196,000
	Subtotal				**$22,517,000**
	General Contractor Overhead, Profit & Risk			15.0%	$3,378,000
	TOTAL ESTIMATED CONSTRUCTION COST				**$25,895,000**
	Engineering, Legal & Administration Fees			15.0%	$3,884,000
	Owner's Reserve for Change Orders			5.0%	$1,295,000
	TOTAL ESTIMATED PROJECT COST				**$31,074,000**

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T3 Tertiary Filtration for N and P removal

Date : February-18
By : MRM
Reviewed: BJL

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	N-removal (1-2 gpm/sf per ADMMF)	1	LS		$ 4,793,000
	P-removal (3-5 gpm/sf per PDF)	1	LS		$ 2,544,000
	General Conditions	10%	%		$ 734,000
	TOTAL DIRECT COST				**$8,071,000**
	Contingency			30.0%	$2,421,000
	Subtotal				**$10,492,000**
	General Contractor Overhead, Profit & Risk			15.0%	$1,574,000
	TOTAL ESTIMATED CONSTRUCTION COST				**$12,066,000**
	Engineering, Legal & Administration Fees			15.0%	$1,810,000
	Owner's Reserve for Change Orders			5.0%	$603,000
	TOTAL ESTIMATED PROJECT COST				**$14,479,000**

DETAILED COST ESTIMATE

Project: **SF_Nutrient Study**
Client: **City of Santa Fe, NM**
Location: **Santa Fe, NM**
Element: **T4 MF/RO Treatment**

Date : **February-18**
By : **MRM**
Reviewed: **BJL**

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	MF Equipment Cost	1	LS		$ 12,538,000
	MF Electrical & Instrumentation	1	LS		$ 1,879,000
	MF Mechanical	1	LS		$ 1,879,000
	MF membranes Total				
	RO Equipment Cost	1	LS		$ 18,807,000
	RO Electrical & Instrumentation	1	LS		$ 2,821,000
	RO Mechanical	1	LS		$ 2,821,000
	RO membranes Total				
	Modifications to existing facility (reuse existing filter building)	1	LS		$ 200,000
	Deep well injection	1	LS		$ 5,329,000
	General Conditions	5%			$ 2,047,000
			TOTAL DIRECT COST		**$48,321,000**
			Contingency	30.0%	$14,496,000
			Subtotal		**$62,817,000**
			General Contractor Overhead, Profit & Risk	15.0%	$9,423,000
			TOTAL ESTIMATED CONSTRUCTION COST		**$72,240,000**
			Engineering, Legal & Administration Fees	15.0%	$10,836,000
			Owner's Reserve for Change Orders	5.0%	$3,612,000
			TOTAL ESTIMATED PROJECT COST		**$86,688,000**

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T3 Chemical Feed Facilities (Bypass

Date : February-18
By : MRM
Reviewed: BJL

SPEC. NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	Metal Salt Feed Facility	1	LS	$ 634,950	$ 634,950
	Carbon feed facility	1	LS	$ 770,100	$ 770,100
	Mechanical modifications	5%	%		$ 70,000
	EI&C	15%	%		$ 221,000
	General Conditions	10%	%		$ 170,000
			TOTAL DIRECT COST		**$1,866,000**
			Contingency	30.0%	$560,000
			Subtotal		**$2,426,000**
			General Contractor Overhead, Profit & Risk	15.0%	$364,000
			TOTAL ESTIMATED CONSTRUCTION COST		**$2,790,000**
			Engineering, Legal & Administration Fees	15.0%	$419,000
			Owner's Reserve for Change Orders	5.0%	$140,000
			TOTAL ESTIMATED PROJECT COST		**$3,349,000**

DETAILED COST ESTIMATE

Project: SF_Nutrient Study
Client: City of Santa Fe, NM
Location: Santa Fe, NM
Element: T3 Tertiary Filtration for N and P removal (Bypass Scenario)

Date : February-18
By : MRM
Reviewed: BJL

	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL
	N-removal (1-2 gpm/sf per ADMMF)	1	LS		$ 3,134,000
	P-removal (3-5 gpm/sf per PDF)	1	LS		$ 1,654,000
	General Conditions	10%	%		$ 479,000
	TOTAL DIRECT COST				**$5,267,000**
	Contingency			30.0%	$1,580,000
	Subtotal				**$6,847,000**
	General Contractor Overhead, Profit & Risk			15.0%	$1,027,000
	TOTAL ESTIMATED CONSTRUCTION COST				**$7,874,000**
	Engineering, Legal & Administration Fees			15.0%	$1,181,000
	Owner's Reserve for Change Orders			5.0%	$394,000
	TOTAL ESTIMATED PROJECT COST				**$9,449,000**

Appendix F

REDMON FULL SCALE OFF GAS ANALYSIS

REDMON
ENGINEERING
COMPANY

Consulting Engineers

PO Box 044258
Racine, Wisconsin 53404-7005
4142)46718993

January 27, 2018

Carollo Engineers
Tanja Rauch-Williams
390 Interlocken Cresent, Suite 800
Broomfield, CO 80021

Re: Santa Fe Wastewater Treatment Plant - Report of Full Scale Offgas Analysis of Membrane Grid Aeration System

Dear Tanja,

Attached please find my report of the full-scale offgas tests conducted in November of this year; on the Sanitaire fine pore membrane disc aeration system at the at the Santa Fe WWTP.

Following your review, should you have any questions, please let me know.

Best regards,

REDMON ENGINEERING COMPANY

David T. Redmon, P.E.

FULL SCALE OFFGAS ANALYSIS
OF THE
SANITAIRE FINE PORE MEMBRANE GRID AERATION SYSTEM
AT THE
SANTA FE WWTP

SANTA FE, NEW MEXICO

PERFORMED ON BEHALF OF:
CAROLLO ENGINEERS

CONDUCTED
November 2017

PERFORMED BY:
REDMON ENGINEERING COMPANY
PO Box 044258
Racine, Wisconsin 53404

(414) 467-8993

REDMON
ENGINEERING COMPANY

FULL SCALE OFFGAS ANALYSIS
OF THE
SANITAIRE FINE PORE MEMBRANE DISC AERATION SYSTEM
AT THE
SANTA FE WASTEWATER TREATMENT PLANT
IN
SANTA FE, NM

December 2017

INTRODUCTION

Redmon Engineering Company was engaged as a subcontractor to Carollo Engineers to conduct an offgas evaluation of the Sanitaire fine pore membrane grid aeration system installed in the aeration basins at the Santa Fe WWTP in Santa Fe, New Mexico. The purpose of the tests was to measure the oxygen transfer efficiency of the existing membrane disc diffusers under process water conditions. A second portion of the aeration study was to conduct a laboratory evaluation of the existing membrane diffusers. This portion of the project is covered by a separate report.

The objective of the offgas evaluation was to provide site-specific measurements of oxygen transfer efficiency, alpha and oxygen transfer rate of the membrane disc aeration system that was installed in the two aeration basins approximately sixteen years ago.

On November 14, 15, and 16, 2017, David Redmon of Redmon Engineering Company conducted offgas tests on the aeration system at the Santa Fe WWTP. The results of this offgas evaluation are presented in this report.

BACKGROUND

The full-scale test involves placing a floating offgas collection device on the liquid surface of the basin(s) in question at various locations and to analyze the exiting gas for the partial pressure of oxygen compared to that of ambient air. In addition, the rate of offgas evolution is typically measured for each offgas collection hood sampling position employed and each test condition. These data are analyzed according to the procedures described in the paper, "Oxygen Transfer Efficiency Measurements in Mixed Liquor Using Offgas Techniques," by Redmon, et al. (WPCF November, 1983) and the ASCE “Standard Guidelines for In-Process Oxygen Transfer Testing,” (ASCE-18-96). The offgas paper is contained in Appendix I for the reader’s reference.

Aeration System

The aeration system tested at the Santa FE WWTP consists of two oxidation ditch aeration basins. Each of the basins is about 120 feet wide by about 260 feet in length and having a side water depth of 16.6 feet. Each basin consists of four channels, with each channel having a width of 29.25 feet. There are six (6) individual grids of membrane disc diffusers along the length of each basin. There are two grids in Channel #1, two grids in Channel #2 and two grids in Channel #3. There are no grids of diffusers installed in Channel #4. There is an approximate total of 3,800 diffusers installed in each basin. Figure 1 is a plan view drawing indicating the general layout of the basin and the diffuser layout. This figure shows that grids 4, 5, and 6 were turned of and not operating.

Test Parameters

The full-scale tests were conducted to measure oxygen transfer efficiency, alpha factor, and oxygen transfer rates under actual operating conditions.

Manufacturers of aeration systems typically quote performance based on clean water oxygen transfer test results. To compare data, the tests should best be conducted in large-scale tanks in accordance with standard procedures (ASCE Clean Water Test Standard, 1992). For a given basin geometry, diffuser type and layout, aeration equipment manufacturers can provide acceptable estimates of clean water standard oxygen transfer efficiency (SOTE) and equilibrium dissolved oxygen (DO) concentration at standard conditions as time approaches infinity ($C^*_{\infty 20}$). Standard conditions of temperature and pressure are 20°C and 1.0 atmosphere of pressure (29.92 in Hg or 760 mm Hg), respectively.

To estimate the oxygen transfer efficiency in the process water under actual operating conditions, the following equation is used (ASCE, 1992):

$$\mathrm{OTE_F} = \alpha(\mathrm{SOTE})(\Theta^{T-20})(\Upsilon\Omega\beta C^*_{\infty 20} - C) / C^*_{\infty 20}$$

Where:

OTE_F = Process water oxygen transfer efficiency, mass fraction of oxygen transferred per unit of oxygen supplied, decimal fraction.

α = Alpha, the ratio of mass transfer coefficients, process water to clean water, decimal fraction.

Θ = Mass transfer coefficient temperature correction factor, generally taken to be 1.024, dimensionless.

T = Temperature of the process water, °C.

Υ = Temperature correction factor (C^*_{bST}/C^*_{b20}) of the steady state DO saturation concentration, dimensionless.

Where:

C^*_{bST} = Tabulated DO surface saturation value at temperature T, taken from Standard Methods, mg/l.

C^*_{b20} = Tabulated DO surface saturation value at 20°C taken from Standard Methods, mg/l.

β = Ratio of steady state DO saturation concentration in process and clean water, dimensionless (basis total dissolved solids).

Ω = Pressure correction factor (P_b/P_s) for the steady state DO saturation concentration, dimensionless.

Where:

P_b = Local barometric pressure for the site, in Hg.
P_s = Standard barometric pressure, 29.92 in Hg (101.3 k Pa).

C = Dissolved oxygen concentration averaged over process water volume being evaluated, mg/l.

All of the factors involved in the conversion from clean water to process water, except alpha, and the fouling factor can be reasonably estimated from published or assumed values. The field studies were conducted at the Santa Fe WWTP in an effort to provide site-specific estimates of OTE and alpha(F), as well as OUR, for use in assessing the aeration performance of the aeration system under process water conditions.

RESULTS

General

The results of the full-scale offgas evaluation is summarized as Tables 1, 2, and 3. The field data sheets from which the summary tables were developed are contained in Appendix II. As mentioned earlier, Figure 1 is a plan view of one of the aeration basins and shows layouts of the fine bubble grid diffusers. Figure 2 shows the locations of the offgas collection hood sampling positions used in this evaluation. The offgas collection hood used was two feet wide by eight feet in length, thus having a total capture area of 16 square feet.

Table 1 summarizes the offgas results obtained on November 14, 2017. The first several columns of this table, including time, sampling station designation, mixed liquor temperature, gas-phase sensor output (Mog and Mr), DO concentrations (C), and offgas flow rate are obtained from the field data sheets. Knowing the dissolved oxygen (DO) saturation value from clean water testing of the equipment in question (C^*_{20}), the field saturation value (C^*_f) can be estimated by applying corrections for local atmospheric pressure, mixed liquor temperature and total dissolved solids, which are reflected in the beta factor. The column headed C^*_f-DO (Column 7) represents the DO driving force (saturation minus the DO concentration) at that sampling station.

Columns 8 and 9 are the float heights (in millimeters) for the two rotameters measuring offgas flow rate. Column 10 is the collection area of the offgas collection hood. Column 11 lists the measured offgas flux for the sample location in question. The offgas flux is determined by dividing the offgas flow rate by the offgas collection hood area (Column 10).

Column 12 is the calculated airflow per diffuser and is determined by dividing the offgas flux (scfm per square foot) by the diffuser density (the number of diffusers per square foot) beneath the hood.

Column 13 lists the total airflow to each of the test zones in the basin in question. In each zone the average offgas flux times the surface area of the zone in question yields an estimate of the total airflow to the zone in question. The total airflow for each cell and the basin overall is obtained by summing the estimated airflow in each zone.

The gas-phase oxygen transfer efficiency under process conditions is given by the columns headed OTE_F (Column 14), OTE_{SP20} (Column 15) and SOTEpw (Column 16). The field oxygen transfer efficiency (OTE_F) is the actual gas-phase transfer, as a decimal, under existing field conditions of DO concentration, barometric pressure, total dissolved solids, mixed liquor temperature and prevailing operating mode. OTE_{SP20} is the transfer efficiency per each mg/l of driving force, corrected to a 20°C mixed liquor temperature. SOTEpw is the oxygen transfer efficiency in process water corrected to standard conditions of one atmosphere of pressure, zero DO concentration and 20°C.

Column 17, SOTEcw, is an estimate of the clean water oxygen transfer efficiency based on the Sanitaire clean water test database.

Column 18 is the ratio of SOTEpw to SOTEcw. When diffusers are new this ratio is known as alpha. In this case, the aeration system had been in operation for many years so the ratio of SOTEpw to SOTEcw is known as alpha(F), where F is a fouling factor. The fouling factor accounts for changes in diffuser oxygen transfer efficiency due to fouling and changes in the membrane properties. When the diffusers are new the fouling factor is unity (1.00). Column 19 is the computed oxygen uptake rate (OUR) for each hood location based on a gas-phase mass balance. The mass balance calculation procedure used to calculate the OUR is presented in Appendix III.

Listed at the bottom of each table are the overall average values of DO concentration, offgas flux, diffuser air flow, alpha and oxygen uptake rate along with the total air flow and the mean weighted average OTE_F and SOTEpw values for the entire basin.

Test Results

The first set of offgas data was obtained on Tuesday, November 14, 2017. Table 1 summaries of the offgas results for the first day of testing. Looking at the first line of data, it is seen that the first sample location (1.1N – Channel #1, hood location #1, in the North (N) Basin) was tested at 1026 hours. The mixed liquor temperature was 20.4

degrees Celsius and the dissolved oxygen concentration was 0.55 mg/l. The offgas flux for this location was observed to be 0.215 scfm per square foot of surface area, which is equivalent to an airflow rate of approximately 0.68 scfm per diffuser. The field oxygen transfer efficiency for sample location 1.1N is 21.74% when corrected to standard conditions is 29.51%. The alpha(F) value for this location is computed to be 0.66 and the oxygen uptake rate (OUR), based on the gas-phase mass balance, is 46.8 mg/l/hr. The results for each of the remaining test locations are presented in a similar matter.

At the bottom of each section of data is listed the average DO concentration, offgas flux, airflow per diffuser average transfer efficiency, alpha(F), and average oxygen uptake rate. Also presented is the total airflow to grid being tested. In Table 1 the first section of data only contains three hood locations in the first grid of Channel #1. These data points were gathered between 1025 hours and 1049 hours. Shortly after 1049 hours the airflow rate to the system was approximately doubled. As a result, the testing of the first grid in Channel #1 was restarted.

The second set of data in Table 1 is from the first grid in Channel #1 of the North Aeration Basin, while the third dataset in from the first grid in Channel #1 of the South Basin. It should be pointed out that the first grid in the North Aeration Basin had new membrane disc diffusers installed when the basin was recently drained and repaired, while the first grid in the South Aeration Basin had the original diffusers still installed in the grid. The summary data at the bottom of sections two and three (in red ink) indicate that the membranes in the first grid of the North Basin are more efficient than those installed in the South Basin. The overall average SOTEpw for the North Basin was observed to be 25.8% compared to 23.6% for the South Basin, even though the North Basin grid was operating at about 1.4 scfm per diffuser, while the South Basin was running at about 1.07 scfm per diffuser. Generally, the higher the airflow per diffuser, the lower the oxygen transfer efficiency. The data suggest that the North Basin grid is operating about 9.5% more efficient than the South Basin grid. The computed value of alpha for the new membranes (first grid in the North Basin) is 0.68, while the alpha(F) value for the first grid in the South Basin is 0.59. These are some of the highest alpha values measured by this writer, who has been conducting offgas analyses for over thirty-five years.

It was observed that there was a significant horizontal velocity in the channels due to the Banana Blade mixers installed in each basin. The writer was involved in a study in France that documented the improvement in fine bubble grid efficiency as a function of horizontal velocity across the fixed grids. This paper generated as a result of this study is contained in Appendix IV of this report. The results of this study in clean water demonstrate an oxygen transfer efficiency improvement at a horizontal velocity of about 1.2 feet per second on the order of 40%. In process water the improvement was approximately 20%. At lower velocities the improvement was less, but significant. Observations of the bubble patterns indicate that the horizontal velocity was on the order of about 1.0 to 1.5 feet per second. A differential velocity across the air discharge surfaces of the diffusers results in the bubbles being released from the diffusers at a smaller diameter due to the shear forces of the water flowing across the diffuser. This results in smaller bubbles with more interfacial area and lower rise rates, as smaller bubbles are less buoyant and therefore rise less quickly than do larger bubbles.

Table 2 is from Wednesday November 15th. On this day grid #3 in the North Basin was tested, and gird #1 of the North Basin was re-tested to see how consistent the offgas results were from one day to the next. The results of the re-test of grid #1 show nearly the same results as the previous day. The SOTEpw was observed to be 25.4% at an airflow of 960 scfm, compared to an SOTEpw of 25.8% at an airflow of 893 scfm. The alpha for grid #1 on day two was 0.64, compared to 0.68 on day one.

Grid #3 in the North Basin was observed to have an overall average SOTEpw of 22.8% at an airflow of 799 scfm. This results in a computed alpha(F) value of 0.60. Grid #3 also had the original membrane disc diffusers installed on the grid in question.

On the third day of testing (November 16th) grid #2 in the North Basin was tested. The overall average SOTEpw was observed to be 27.0% at an airflow of 900 scfm. This results in an alpha value of 0.71. This grid also has new membrane diffusers that were installed when the basin was drained to make repairs.

Table 4 is a summary of the offgas results comparing the performance of the new membrane disc diffusers against those grids with the original membranes still installed in them. The summary shows an average SOTEpw of 26.07% for the new membranes and 23.20% for the old membranes.

The writer believes the presence of significant horizontal liquid velocity across the fixed grids of fine bubble diffusers has resulted in enhanced oxygen transfer, when compared with fixed grids without velocity. This is the most likely reason for the high alpha values observed in the Santa Fe aeration basins. Field oxygen transfer efficiencies (corrected to standard conditions) under process water conditions in the range of 22% to 27% at a diffuser submergence of 16.6 feet are typically unheard of. These are transfer efficiencies in the range of 1.3 to 1.6% per foot of submergence, under process water conditions.

The writer has also observed that in looped reactors (oxidation ditches) that alpha values are nearly constant throughout the basin, as the loop time compared to the hydraulic retention time, is so small that the basin approaches that of a complete mix reactor.

The results are in general agreement with the laboratory diffuser tests, which indicated the used membranes, when tested head-to-head against new membranes, showed a loss in efficiency of about 6.2%. The existing membrane diffusers are approaching seventeen years old. If significant aeration system revisions are to occur in the future the best course of action would be to replace all of the diffusers with new membranes.

TABLE 1

SUMMARY DATA SHEET - FULL SCALE OFFGAS TESTS

DATE: November 14, 2017

SITE: SANTA FE, NM
SYSTEM: SANITAIRE MEMBRANES
SUBMERGENCE: 15.60 FT.
SWD: 16.60 FT.
DIFFUSERS/BASIN:

MLSS: 3,300 MG/L
MLVSS: MG/L
TDS: 1,000 MG/L (ASSUMED)
SRT: 12 DAYS
TOTAL AIR RATE: SCFM

LOCAL BAROMETER: 23.92 in. Hg.
BETA: 0.98
C^*_{20}: 10.70 MG/L
C^*_F: 8.20 MG/L

H_R: 0.00
H_{OG}: 0.00 LB H_2O/LB
B.D. AIR
CO_2: 0.00

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
TIME	STATION	ML TEMP °C	M(og) (mv)	M(r) (mv)	C (mg/l)	C^*_F-C (mg/l)	Rmm 1	Rmm 2	HOOD AREA (sq ft)	OFFGAS FLUX (scfm/sq ft)	SCFM PER DIFFUSER	TOTAL AIR FLOW (cfm)	OTE_F (decimal)	OTE_{SP20} (decimal)	SOTEpw	SOTEcw	ALPHA(F)	OUR (mg/l/hr)
NORTH AERATION BASIN - GRID 1																		
1025	1.1N	20.4	826	1007	0.55	7.65	133	0	16	0.215	0.68	145	0.2174	0.02815	0.2951	0.370	0.80	46.8
1037	1.2N	20.4	809	1009	0.55	7.65	98	0	16	0.163	0.52	110	0.2381	0.03083	0.3233	0.370	0.87	38.8
1049	1.3N	20.4	796	1011	0.60	7.60	134	0	16	0.217	0.69	147	0.2547	0.03320	0.3481	0.370	0.94	55.3
					$\bar{X}$ =					$\bar{X}$ =	$\bar{X}$ =	Σ =	MWA =		MWA =	$\bar{X}$ =	$\bar{X}$ =	$\bar{X}$ =
					0.57					0.198	0.63	402	0.2367		0.3222	0.370	0.87	47.0
NORTH AERATION BASIN - GRID 1																		
1334	1.1N	20.4	871	1000	1.20	7.00	0	58	16	0.436	1.38	147	0.1577	0.02232	0.2341	0.343	0.68	68.8
1309	1.2N	20.4	848	1002	1.30	6.90	230	0	16	0.361	1.15	122	0.1868	0.02682	0.2812	0.343	0.82	67.5
1252	1.3N	20.4	841	1003	1.60	6.60	0	65	16	0.474	1.50	160	0.1955	0.02934	0.3076	0.343	0.90	92.7
1211	1.4N	20.4	877	1002	1.25	6.95	0	80	16	0.556	1.77	188	0.1525	0.02173	0.2278	0.343	0.66	84.8
1225	1.5N	20.4	882	1003	1.65	6.55	0	60	16	0.447	1.42	151	0.1479	0.02237	0.2346	0.343	0.68	66.2
1239	1.6N	20.4	862	1003	1.70	6.50	235	0	16	0.368	1.17	124	0.1717	0.02617	0.2744	0.343	0.80	63.2
					$\bar{X}$ =					$\bar{X}$ =	$\bar{X}$ =	Σ =	MWA =		MWA =	$\bar{X}$ =	$\bar{X}$ =	$\bar{X}$ =
					1.45					0.440	1.40	893	0.1676		0.2581	0.343	0.76	73.9
SOUTH AERATION BASIN -GRID 1																		
1443	1.1S	20.5	871	1001	1.00	7.20	230	0	16	0.361	1.15	122	0.1589	0.02181	0.2287	0.350	0.65	57.4
1456	1.2S	20.5	853	1001	1.00	7.20	200	0	16	0.316	1.00	107	0.1800	0.02471	0.2591	0.350	0.74	56.9
1508	1.3S	20.5	853	999	1.00	7.20	220	0	16	0.347	1.10	117	0.1777	0.02440	0.2558	0.350	0.73	61.7
1520	1.4S	20.5	878	1000	1.00	7.20	235	0	16	0.368	1.17	124	0.1498	0.02056	0.2156	0.350	0.62	55.2
1534	1.5S	20.5	869	1002	1.00	7.20	200	0	16	0.316	1.00	107	0.1623	0.02227	0.2335	0.350	0.67	51.3
1545	1.6S	20.5	875	1002	1.00	7.20	195	0	16	0.308	0.98	104	0.1555	0.02134	0.2238	0.350	0.64	47.9
					$\bar{X}$ =					$\bar{X}$ =	$\bar{X}$ =	Σ =	MWA =		MWA =	$\bar{X}$ =	$\bar{X}$ =	$\bar{X}$ =
					1.00					0.336	1.07	682	0.1638		0.2357	0.350	0.67	55.1

TABLE 2

SUMMARY DATA SHEET - FULL SCALE OFFGAS TESTS

DATE: November 15, 2017

SITE: SANTA FE, NM
SYSTEM: SANITAIRE MEMBRANES
SUBMERGENCE: 15.60 FT.
SWD: 16.60 FT.
DIFFUSERS/BASIN:

MLSS: 3,300 MG/L
MLVSS: MG/L
TDS: 1,000 MG/L (ASSUMED)
SRT: 12 DAYS
TOTAL AIR RATE: SCFM

LOCAL BAROMETER: 23.99 in. Hg.
BETA: 0.98
C^*_{20}: 10.70 MG/L
C^*_F: 8.25 MG/L

H_R: 0.00
H_{OG}: 0.00 LB H_2O/LB
B.D. AIR
CO_2: 0.00

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
TIME	STATION	ML TEMP °C	M(og) (mv)	M(r) (mv)	C (mg/l)	C^*_F-C (mg/l)	Rmm 1	Rmm 2	HOOD AREA (sq ft)	OFFGAS FLUX (scfm/sq ft)	SCFM PER DIFFUSER	TOTAL AIR FLOW (cfm)	OTE_F (decimal)	OTE_{SP20} (decimal)	SOTEpw	SOTEcw	ALPHA(F)	OUR (mg/l/hr)
NORTH AERATION BASIN - GRID 3																		
1033	3.1N	20.1	902	1005	2.95	5.30	0	55	16	0.420	1.15	122	0.1264	0.02380	0.2495	0.347	0.72	53.1
1048	3.2N	20.1	909	1006	2.75	5.50	0	50	16	0.394	1.08	114	0.1189	0.02156	0.2261	0.347	0.65	46.9
1059	3.3N	20.1	911	1007	2.75	5.50	0	60	16	0.447	1.22	130	0.1177	0.02136	0.2240	0.347	0.65	52.7
1118	3.4N	20.1	908	1005	2.45	5.80	0	75	16	0.529	1.45	154	0.1189	0.02045	0.2144	0.347	0.62	62.9
1144	3.5N	20.1	905	1005	2.40	5.85	0	74	16	0.524	1.44	152	0.1223	0.02085	0.2186	0.347	0.63	64.1
1155	3.6N	20.1	900	1007	2.60	5.65	0	58	16	0.436	1.19	127	0.1309	0.02312	0.2424	0.347	0.70	57.1
					$\bar{X}$ = 2.65					$\bar{X}$ = 0.458	$\bar{X}$ = 1.26	Σ = 799	MWA = 0.1224		MWA = 0.2282	$\bar{X}$ = 0.347	$\bar{X}$ = 0.66	$\bar{X}$ = 56.1
NORTH AERATION BASIN - GRID 1																		
1517	1.1N	20.2	873	1006	1.40	6.85	0	65	16	0.474	1.50	160	0.1615	0.02347	0.2461	0.340	0.72	76.6
1507	1.2N	20.2	852	1007	1.45	6.80	0	58	16	0.436	1.38	147	0.1868	0.02734	0.2867	0.340	0.84	81.5
1440	1.3N	20.2	844	1000	1.60	6.65	0	67	16	0.485	1.54	164	0.1894	0.02835	0.2973	0.340	0.87	91.9
1429	1.4N	20.2	878	1001	1.60	6.65	0	75	16	0.529	1.68	179	0.1502	0.02248	0.2357	0.340	0.69	79.5
,1401	1.5N	20.2	887	1002	1.75	6.50	0	62	16	0.458	1.45	155	0.1408	0.02155	0.2260	0.340	0.66	64.5
1416	1.6N	20.2	879	1001	1.60	6.65	0	62	16	0.458	1.45	155	0.1491	0.02231	0.2339	0.340	0.69	68.3
					$\bar{X}$ = 1.57					$\bar{X}$ = 0.473	$\bar{X}$ = 1.50	Σ = 960	MWA = 0.1627		MWA = 0.2539	$\bar{X}$ = 0.340	$\bar{X}$ = 0.75	$\bar{X}$ = 77.1

TABLE 3

SUMMARY DATA SHEET - FULL SCALE OFFGAS TESTS

DATE: November 16, 2017

SITE: SANTA FE, NM
SYSTEM: SANITAIRE MEMBRANES
SUBMERGENCE: 15.60 FT.
SWD: 16.60 FT.
DIFFUSERS/BASIN:

MLSS: 3,300 MG/L
MLVSS: MG/L
TDS: 1,000 MG/L (ASSUMED)
SRT: 12 DAYS
TOTAL AIR RATE: SCFM

LOCAL BAROMETER: 23.94 in. Hg.
BETA: 0.98
C^*_{20}: 10.70 MG/L
C^*_F: 8.30 MG/L

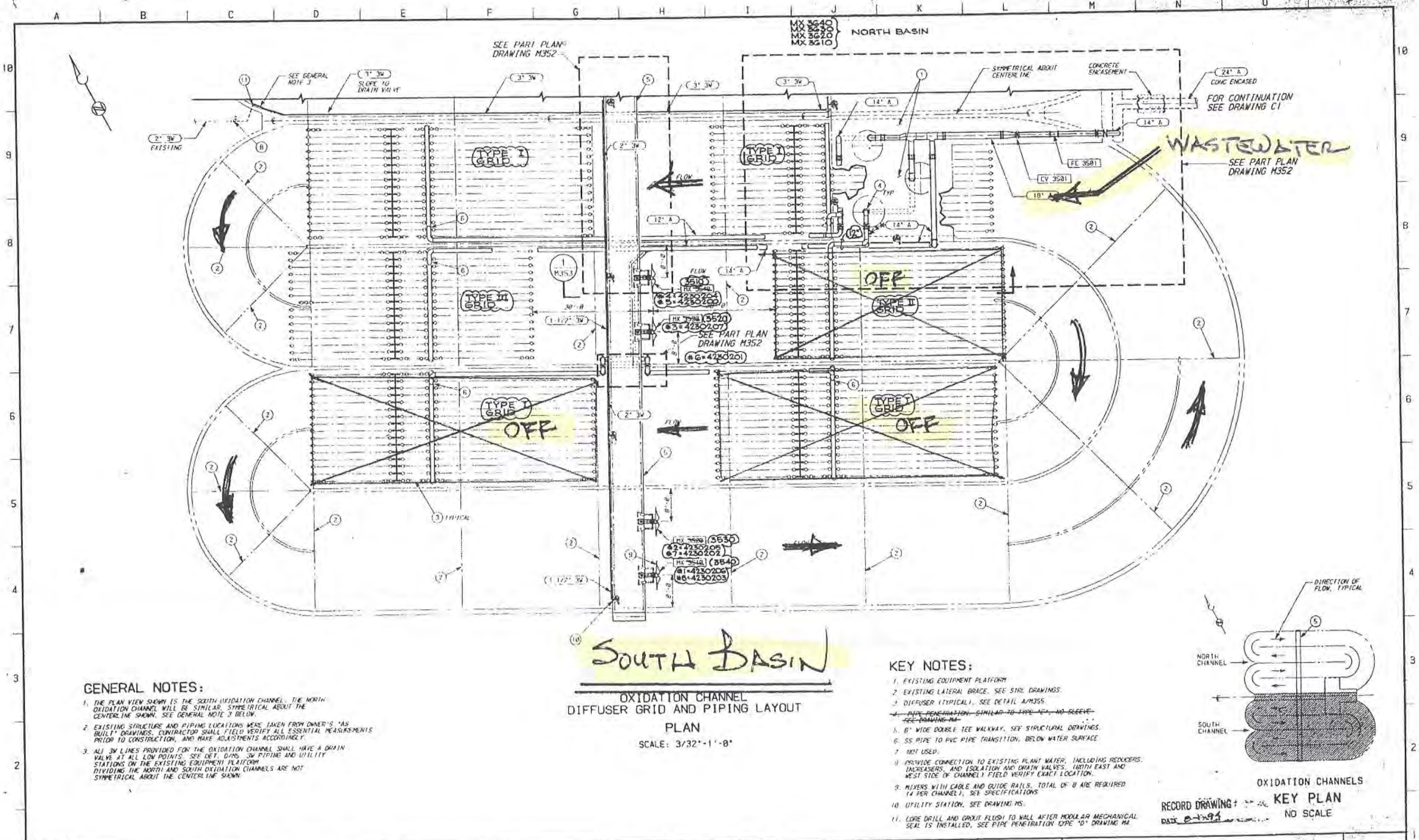
H_R: 0.00
H_{OG}: 0.00 LB H_2O/LB
B.D. AIR
CO_2: 0.00

1 TIME	2 STATION	3 ML TEMP °C	4 M(og) (mv)	5 M(r) (mv)	6 C (mg/l)	7 C^*_F-C (mg/l)	8 Rmm 1	9 Rmm 2	10 HOOD AREA (sq ft)	11 OFFGAS FLUX (scfm/sq ft)	12 SCFM PER DIFFUSER	13 TOTAL AIR FLOW (cfm)	14 OTE_F (decimal)	15 OTE_{SP20} (decimal)	16 SOTEpw	17 SOTEcw	18 ALPHA(F)	19 OUR (mg/l/hr)
NORTH AERATION BASIN - GRID 2																		
1042	2.1N	19.9	886	1003	2.55	5.75	0	58	16	0.436	1.19	127	0.1430	0.02493	0.2614	0.343	0.76	62.4
1103	2.2N	19.9	893	1008	2.50	5.80	0	72	16	0.513	1.41	149	0.1400	0.02420	0.2537	0.343	0.74	71.9
1117	2.3N	19.9	882	1007	2.45	5.85	0	78	16	0.546	1.50	159	0.1521	0.02606	0.2732	0.343	0.80	83.1
1133	2.4N	19.9	882	1005	2.40	5.90	0	76	16	0.534	1.46	155	0.1498	0.02545	0.2669	0.343	0.78	80.1
1154	2.5N	19.9	875	1006	2.25	6.05	0	75	16	0.529	1.45	154	0.1593	0.02639	0.2767	0.343	0.81	84.3
1208	2.6N	20.0	870	1005	2.30	6.00	0	77	16	0.540	1.48	157	0.1638	0.02730	0.2862	0.343	0.83	88.5
					$\bar{X}$ =					$\bar{X}$ =	$\bar{X}$ =	Σ =	MWA =		MWA =	$\bar{X}$ =	$\bar{X}$ =	$\bar{X}$ =
					2.41					0.516	1.41	900	0.1517		0.2701	0.343	0.79	78.4

TABLE 4 - OVERALL SUMMARY SANTA FE WWTP

Date	Basin	Grid	Diffuser Age	Airflow to Grid (scfm)	SOTEpw (%)
14-Nov	North	1	New	402	32.22
14-Nov	North	1	New	893	25.81
14-Nov	South	1	Old	682	23.57
15-Nov	North	3	Old	799	22.82
15-Nov	North	1	New	960	25.39
16-Nov	North	2	New	900	27.01
	Average		New		26.07
	Average		Old		23.20
	Ratio: New/Old				**1.124**

FIGURE 1 - SANTA FE
PLAN VIEW & DIFFUSER LAYOUT



OXIDATION CHANNEL DIFFUSER GRID AND PIPING LAYOUT

PLAN

SCALE: 3/32"-1'-0"

GENERAL NOTES:

1. THE PLAN VIEW SHOWN IS THE SOUTH OXIDATION CHANNEL. THE NORTH OXIDATION CHANNEL WILL BE SIMILAR, SYMMETRICAL ABOUT THE CENTERLINE SHOWN, SEE GENERAL NOTE 3 BELOW.
2. EXISTING STRUCTURE AND PIPING LOCATIONS WERE TAKEN FROM OWNER'S "AS BUILT" DRAWINGS. CONTRACTOR SHALL FIELD VERIFY ALL ESSENTIAL MEASUREMENTS PRIOR TO CONSTRUCTION, AND MAKE ADJUSTMENTS ACCORDINGLY.
3. ALL 3W LINES PROVIDED FOR THE OXIDATION CHANNEL SHALL HAVE A DRAIN VALVE AT ALL LOW POINTS. SEE DET. D/M5. 3W PIPING AND UTILITY STATIONS ON THE EXISTING EQUIPMENT PLATFORM DIVIDING THE NORTH AND SOUTH OXIDATION CHANNELS ARE NOT SYMMETRICAL ABOUT THE CENTERLINE SHOWN.

KEY NOTES:

1. EXISTING EQUIPMENT PLATFORM
2. EXISTING LATERAL BRACE. SEE STRL DRAWINGS.
3. DIFFUSER (TYPICAL). SEE DETAIL A/M355.
4. ~~PIPE PENETRATION, SIMILAR TO TYPE "E", NO SLEEVE. SEE DRAWING M4~~
5. 8' WIDE DOUBLE TEE WALKWAY. SEE STRUCTURAL DRAWINGS.
6. SS PIPE TO PVC PIPE TRANSITION, BELOW WATER SURFACE
7. NOT USED.
8. PROVIDE CONNECTION TO EXISTING PLANT WATER, INCLUDING REDUCERS, INCREASERS, AND ISOLATION AND DRAIN VALVES. (BOTH EAST AND WEST SIDE OF CHANNEL) FIELD VERIFY EXACT LOCATION.
9. MIXERS WITH CABLE AND GUIDE RAILS. TOTAL OF 8 ARE REQUIRED (4 PER CHANNEL). SEE SPECIFICATIONS.
10. UTILITY STATION. SEE DRAWING M5.
11. CORE DRILL AND GROUT FLUSH TO WALL AFTER MODULAR MECHANICAL SEAL IS INSTALLED. SEE PIPE PENETRATION TYPE "D" DRAWING M4

OXIDATION CHANNELS
KEY PLAN
NO SCALE

RECORD DRAWING
DATE 8-1-94

15-486 8-5-91

BROWN AND CALDWELL
Consultants
Phoenix, Arizona

LINE IS 2 INCHES AT FULL SCALE

FILE	4132
DRAWN	DRH
DESIGNED	GLG & DHB
CHECKED	PT & GLG
CHECKED	RNW

SUBMITTED: DATE: 8-22-91
APPROVED: DATE: 8-22-91
APPROVED: DATE:

ZONE	REV.	REVISIONS DESCRIPTION	BY	DATE	APP.

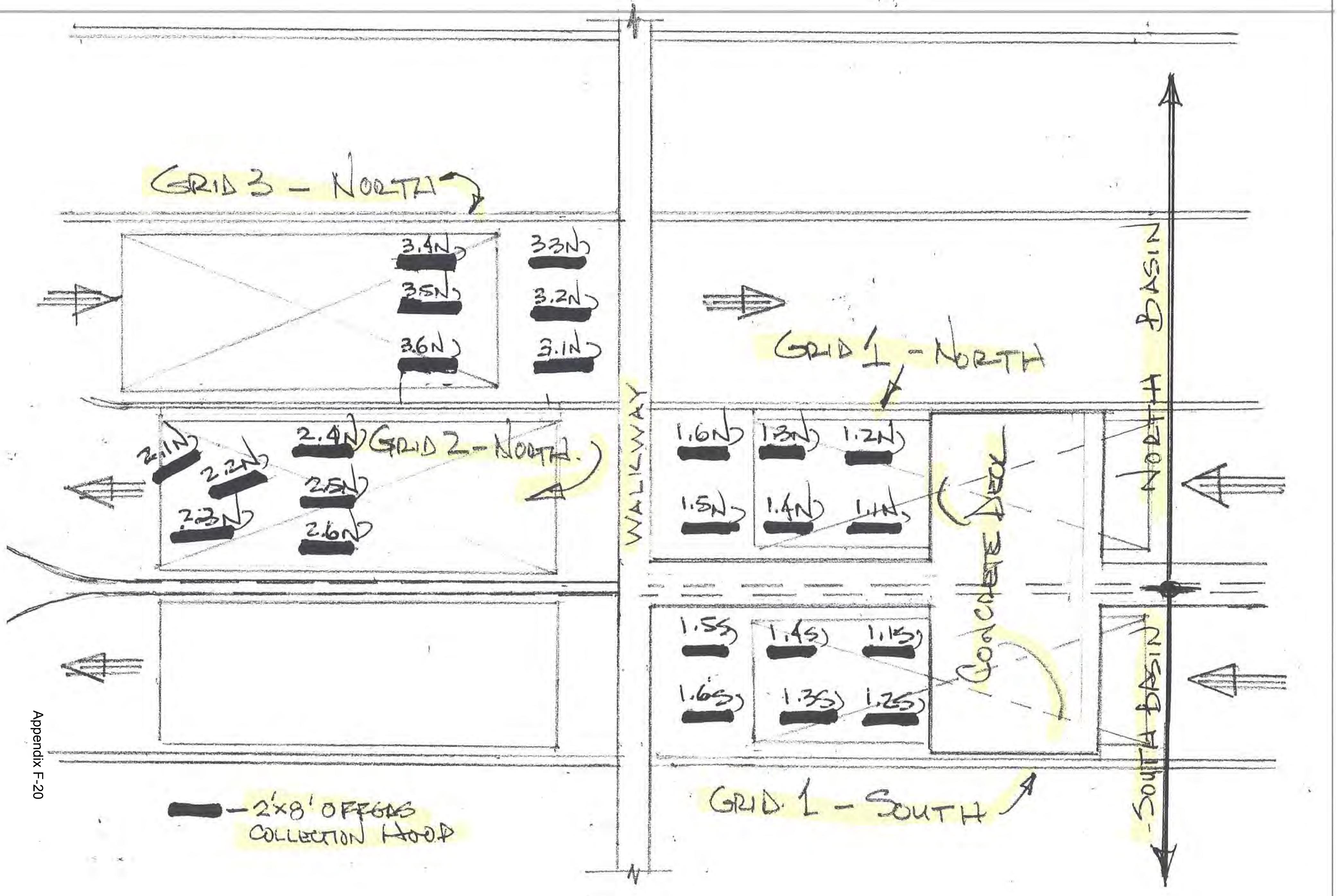
CITY OF SANTA FE
AIRPORT ROAD WASTEWATER TREATMENT PLANT

MODIFICATION / REPLACEMENT PROJECT

OXIDATION CHANNELS
DIFFUSER GRID AND PIPING LAYOUT
PLAN

DRAWING NUMBER M351
SHEET NUMBER 28

FIGURE 2 - OFFGAS SAMPLING PLAN



SYMBOLS AND NOMENCLATURE

DO = Dissolved Oxygen

C = DO concentration, mg/l

C^*_F = DO saturation value applicable for equipment in use and existing conditions, mg/l

$C^*_F - C$ = DO driving force or effective DO deficit, mg/l

$C^*_{\infty 20}$ = DO saturation value in clean water for system tested at standard conditions as time approaches infinity

C^*_{ST} = Tabulated DO surface saturation value at temperature T, taken from Standard Methods, mg/l

C^*_{20} = Tabulated DO surface saturation value at 20 C taken from standard Methods, mg/l

EPDM = E-Ethylene, P-propylene, D-Diene comoners, M-polyMethylene backbone; synthetic rubber

AOTR = Actual Oxygen Transfer Rate in process water at existing conditions

fpm = Feet per minute

gpm = Gallons per minute

Hg = Mercury

Hood Area = Offgas Hood Collection Area, square feet

K_La = Apparent volumetric mass transfer coefficient of oxygen in clean water and/or process water

MLSS = Mixed Liquor Suspended Solids, mg/l

MLT = Mixed Liquor Temperature, °C

M(og) = Gas phase oxygen sensor output in millivolts for offgas stream

M(r) = Gas phase oxygen sensor output in millivolts for reference stream

MWA = Mean weighted average

Offgas Flux Rate = Rate of offgas evolution per square foot of collection area as measured by offgas rotameters, scfm/sq ft

OTE_F = Process water oxygen transfer efficiency, mass fraction of oxygen transferred per unit of oxygen supplied, decimal fraction

OTE_{SP20} = Oxygen Transfer efficiency per each mg/l of driving force under Standard Conditions

OUR = Oxygen Uptake Rate by mixed liquor, mg/l/hr

P_b = Local barometric pressure for the site, in Hg

P_s = Standard barometric pressure, 29.92 in Hg

Rmm 1 & Rmm 2 = Float Height in millimeters, from scale, for rotameters 1 and 2 in offgas analyzer scfm = Air flow rate, Standard cubic feet per minute

SOTE = Standard Oxygen Transfer efficiency at 20°C and zero DO

SOTEcw = Standard Oxygen Transfer efficiency at Standard Conditions and zero DO in clean water

SOTEpw = Standard Oxygen Transfer efficiency at Standard Conditions and zero DO in process water

SOTR = Standard Oxygen Transfer Rate in clean water at 20°C and zero DO

SRT = Solids Retention Time or Sludge Age, days

Standard Conditions= Barometric Pressure of 29.92 in Hg and 20°C

Submergence = Height of liquid above diffusers, feet

T = Temperature, °C

TDS = Total Dissolved Solids in mixed liquor, mg/l

wg = Water gauge

α = Alpha, the ratio of mass transfer coefficients (KLa), or standard oxygen transfer efficiency, process water to clean water, decimal fraction

β = Beta, the ratio of steady state DO saturation concentration in process and clean water, dimensionless (basis total dissolved solids)

Ω = Pressure correction factor (P_b/P_s) for the steady state DO saturation concentration, dimensionless

Θ = Mass transfer coefficient temperature correction factor, generally taken to be 1.024, dimensionless

Υ = Temperature correction factor (C^*_{ST}/C^*_{20}) for the steady state DO saturation concentration, dimensionless

APPENDIX I

1983 OFFGAS PAPER
BY
REDMON, ET. AL.

Oxygen transfer efficiency measurements in mixed liquor using off-gas techniques

David Redmon, William C. Boyle, Lloyd Ewing

It has been reported that approximately 1.75 million hp of aeration equipment is currently in place on the North American continent, in both municipal and industrial treatment facilities.[1] These facilities are being operated at a power cost exceeding $0.6 billion per year. Evidence suggests that the overall oxygen transfer efficiency for this equipment is low and the cost of power could be reduced by as much as 50% by improved design and operation.[1] Although there are many reasons for imperfect application of oxygen transfer devices in wastewater, one basic cause has been the unavailability of, or failure to use, optimal methods for the measurement of oxygen transfer.

The off-gas measurement technique may be a tool for obtaining more useful design data for aeration systems.

Consensus procedures for testing oxygen transfer devices in clean water are being developed.[2–4] Adequate test procedures for the assessment of aeration equipment under actual process conditions are less developed at this time. Several methods have been employed over the years to evaluate oxygen transfer in suspended growth systems. In a detailed review of these dirty water test procedures, the American Society of Civil Engineers (ASCE) Committee on Oxygen Transfer Standards outlined the assumptions required for these methods and the limitations for each procedure.[5,6] Table 1 briefly summarizes some of these constraints.

Most field test procedures may be classified according to two criteria: the presence or absence of wastewater flow (continuous versus batch tests); the rate of change of dissolved oxygen (DO) in the test volume (steady state versus unsteady state tests). In general, steady state tests are simpler to perform than unsteady state tests, but they do not provide an estimate of the effective DO saturation value in submerged aeration systems. Both procedures require an accurate determination of oxygen uptake rate (OUR) and test volume dissolved oxygen (DO) concentrations that are constant and greater than zero. In an effort to improve the accuracy of the OUR measurement and to ensure steady state conditions within the test cell with respect to DO, flow, and OUR, batch endogenous tests may be performed. These tests, however, often do not realistically project operating conditions.

Several other test procedures for field oxygen transfer are proposed to overcome some of these limitations. Tracer test methods have been used in both clean and dirty water oxygen transfer tests.[6–8] Although the procedure is very extensive and costly, the results obtained with this method are very precise and presumably accurate. The method does not require complete mixing in the test volume or aeration tank DO values greater than zero. In submerged aeration systems, however, this method suffers the same disadvantage as other steady state tests, which is the inability to estimate the effective DO saturation value.

The performance of a mass balance on oxygen in the gas phase under process conditions has been referred to as the off-gas method. This procedure offers a number of advantages over more traditional techniques currently used for this purpose. This paper describes this method, discusses its limitations, and provides data on recently conducted field studies.

HISTORICAL PERSPECTIVE

The use of off-gas measurements in biological reactors is not a new concept. Initially, off-gas analyses were performed to estimate the respiratory demand of biological cultures. As early as 1939, Sawyer and Nichols[9] described a volumetric method used in a closed system to determine the *in situ* oxygen uptake of activated sludge in the laboratory. Hoover *et al.*[10] in 1954 described a method of aeration control in a fermentation system using a paramagnetic oxygen analyzer developed earlier by Pauling *et al.*[11] Pirt and Callow[12] also used *in situ* respiratory demand measurements in studies on the continuous production of butanediol. Both oxygen and CO_2

OFFGAS PAPER

ERRATA: Page 1339

- In Equation (1), substitute $V\rho'\frac{dC}{dt}$ for $V\rho\frac{d\bar{Y}}{dt}$
- Substitute " = " for " − " between Y_{og} and K_La
- Add Definition of ρ' = density of liquid
  after ρ = density of oxygen

Table 1—Assumptions and limitations for dirty water oxygen transfer testing.

Major assumptions	Limitations
Test cell DO constant (spatial/temporal)	Estimate of OUR
Influent flow to cell constant	Estimate of effective DO saturation value
Influent DO to cell constant	DO must be greater than zero
Test cell OUR constant	Test performed under true process conditions
Effective $K_L{}^a$ in cell constant	

were monitored by Orsat analysis. Some of the first field studies that were reported on the use of off-gas techniques to evaluate aeration devices under process conditions were outlined by Downing[13] and Downing *et al.*[14] In this method, oxygen was captured with a light hood covering all or a portion of the aeration tank [capture areas varied from 2.3 to 13.8 m^2 (25 to 149 sq ft)] and the captured oxygen was determined with a paramagnetic oxygen analyzer. These authors calculated the effective overall transfer rate ($\alpha K_L a$), therefore, both captured gas flow rate and equilibrium saturation DO had to be estimated. Gas flow rate was measured by CO_2 injection and material balance calculation. The DO saturation value for these diffused air systems was calculated by a mid-depth correction. Barker *et al.*[15] described an off-gas method used to estimate the oxygen transfer efficiency of a turbine aerator under process conditions. An inverted 0.2-m^3 (55-gal) drum was used to capture the off-gas. Oxygen was determined by a paramagnetic oxygen analyzer and transfer was expressed as percent oxygen transfer efficiency (OTE). Off gas methods were also described by Conway and Kumke[16] for analyzing a sparged turbine in clean water. Similar to the method of Barker *et al.*, off-gas was captured with a 0.2-m^3 (55-gal) container. Gas analyses were performed by both a mass spectrometer and a direct reading oxygen analyzer. Results were reported as percent OTE. Leary *et al.*[17,18] conducted extensive off-gas analyses of the Milwaukee Jones Island aeration tanks from 1967 to 1968. A 46-cm (18-in.) diameter hood was used to collect off-gas, and analyses were performed using both Orsat and gas chromatographic techniques. Data was reported as both percent OTE and $\alpha K_L a$. More recently, off-gas techniques have again been proposed as a procedure for aeration control in field installations[19,20] completing the cycle initiated by Hoover *et al.* in 1954.

THEORETICAL DEVELOPMENT

The oxygen transfer capability of a submerged air device may be estimated by means of a gas phase mass balance over the aerated volume. A number of assumptions may be made to simplify this analysis. These include the following:

- Inerts, including nitrogen are conservative; that is, there is no net absorption or desorption of the constituents in question;
- There is negligible denitrification at the test location;
- The air flow rate to the basin is constant during the test;
- The barometric pressure is constant during the test,
- The off-gas humidity is equivalent to the saturated value at mixed liquor temperature where the latter is less than the instrument inlet temperature, though in other cases it will be equivalent to the saturated value at the instrument inlet temperature; and
- Negligible oxygen transfer is taking place at the liquid surface.

Referring to Figure 1, a gas phase mass balance over the liquid volume, V, may be written

$$V\rho \frac{d\bar{Y}}{dt} = \rho q_i Y_R - \rho q_o Y_{og} - K_L a(C^* - C)V \qquad (1)$$

where

ρ = density of oxygen at temperature and pressure at which gas flow is expressed (M/L^3),
q_i, q_o = total gas volume flow rates of inlet and outlet gases (L_3/t),
Y_R, Y_{og} = mole fractions (or volumetric fractions) of oxygen gas in inlet and outlet gases,
$K_L a$ = overall oxygen mass transfer coefficient, $(1/t)$
C^* = saturation concentration of oxygen in test liquid in equilibrium with exit gas (M/L^3),
C = equilibrium concentration of oxygen in test liquid, (M/L^3), and
V = test cell volume (L^3)

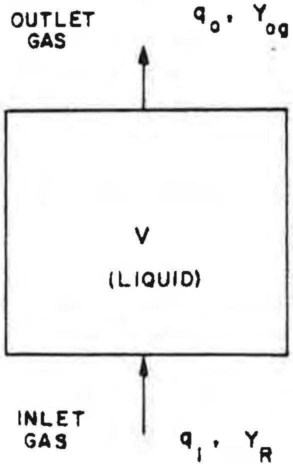


Figure 1—Gas phase mass balance.

At steady state

$$\frac{\rho}{V}(q_iY_R - q_oY_{og}) = K_La(C^* - C) \qquad (2)$$

If one assumes that the volume of CO_2 produced and imparted to the gas stream just equals that of oxygen absorbed, and that nitrogen is conservative, this equation reduces to

$$K_La = \frac{\rho}{V} q \frac{(Y_R - Y_{og})}{(C^* - C)} \qquad (3)$$

where $q = q_i = q_o$

The value of K_La may be estimated from Equation 2 or 3 provided that measurements are made of Y_R and Y_{og}, the inlet and outlet mole fractions of oxygen (q), the total gas flow rate, and C. In addition, an estimate must be made of C^* under test conditions.

Another method of reporting oxygen transfer is by the calculation of OTE expressed as a fraction.

$$\text{OTE} = \frac{\rho q_iY_R - \rho q_oY_{og}}{\rho q_iY_R} \qquad (4)$$

Again, if one assumes CO_2 evolution is equivalent to oxygen absorption, this equation reduces to

$$\text{OTE} = \frac{Y_R - Y_{og}}{Y_R} \qquad (5)$$

Equations 4 and 5 simplify the computation of oxygen transfer in a given system because no estimate of C^* is required, although gas flow rates must be accurately monitored if a correction for CO_2 evolution is to be accounted for in Equation 4.

Gas flow measurements may be omitted from Equation 4 by using molar ratios of inlet and outlet oxygen to the inert gas fractions as given below:

$$\text{OTE} = \frac{\text{mass } O_2 \text{ in} - \text{mass } O_2 \text{ out}}{\text{mass } O_2 \text{ in}}$$

$$= \frac{G_i(M_o/M_i)MR_{o/i} - G_i(M_o/M_i)MR_{og/i}}{G_i(M_o/M_i)MR_{o/i}}$$

and

$$\text{OTE} = \frac{MR_{o/i} - MR_{og/i}}{MR_{o/i}} \qquad (6)$$

where

G_i = mass rate of inerts (including nitrogen & argon) (M/t),
M_o, M_i = molecular weights of oxygen and inerts, and
$MR_{o/i}$, $MR_{og/i}$ = mole ratio of oxygen to inerts in inlet and in off-gas.

The mole ratio of oxygen to inerts may be expressed by Equations 7 and 8 as

$$MR_{o/i} = \frac{Y_R}{1 - Y_R - Y_{CO_2(R)} - Y_{W(R)}} \qquad (7)$$

and

$$MR_{og/i} = \frac{Y_{og}}{1 - Y_{og} - Y_{CO_2(og)} - Y_{W(og)}} \qquad (8)$$

where

$Y_{CO_2(R)}$, $Y_{CO_2(og)}$ = mole fractions of CO_2 in inlet gas (R) or off-gas (og), and
$Y_{W(R)}$, $Y_{W(og)}$ = mole fractions of water vapor in inlet gas (R) or off-gas (og).

Equations 7 and 8 may be substituted into Equation 6 to estimate OTE. It may be noted in the rare case that the mole fraction of CO_2 produced just equals that of oxygen absorbed, Equations 6, 7 and 8 reduce to Equation 5.

Finally, the value of Y_{og} and Y_R may be calculated as follows:

$$Y_R = 0.2095\,(1 - Y_{W(R)}) \qquad (9)$$

and

$$Y_{og} = \left(\frac{MV_{(og)}}{MV_{(R)}}\right)Y_R \qquad (10)$$

where a sensor with linear response of millivolts to partial pressure of oxygen is used and where $MV_{(og)}$, $MV_{(R)}$ are the millivolt output readings of the oxygen sensor, which have been corrected as required for absolute sensor cell pressures and temperatures.

Additional refinements in these equations for nitrogen solution or volatilization may also be made, but preliminary calculations indicate that this correction is minor and may normally be omitted from the calculations.

INSTRUMENTATION

There seems to be general agreement among investigators that off-gas techniques offer substantial advantages over most other procedures for determining oxygen transfer efficiencies for submerged aeration systems under process condition. The greatest drawbacks have been related to the instrumentation. Two practical problems had to be overcome to make the method more acceptable. The first was the need for a gas collection device that was light and easy to handle, but large enough to collect a representative off-gas sample. The early work reported by Downing[13] indicated that the smaller the hood the more variable was the measurement of K_La. The second problem was the selection of an oxygen sensor that could precisely detect small differences in the partial pressure of oxygen, and be adaptable to *in situ* measurements. Over the years investigators have employed gas chromatography, paramagnetic oxygen analyzers and, more recently, polarographic probes and electrochemical galvanic cells.

The four major components of the off-gas equipment used in this investigation were a floating hood to capture the gas, a hose connecting the hood to the analytical circuit, an analytical circuit for monitoring off-gas composition, temperature, pressure, and gas flow rate, and a vacuum source to draw gas from the hood through the analytical circuit.

The hood used for these studies was a section of a 0.6-m (2-ft) diameter pipe cut longitudinally along the pipe diameter to a length of 2.67 m (8.75 ft), to provide a surface capture area of 1.62 m^2 (17.5 sq ft). The hood was provided with ballast tanks to ensure that it remained stable within a given sampling cross section. A 38-mm (1.5-in.) diameter connecting host carried the exhaust gases to an analytical circuit. Pressure under the hood was monitored by means of plastic tubing leading from a port on the hood to the analytical circuit. Suction of exhaust gas from the hood was provided by a vacuum cleaner. The suction line was valved to maintain a small, but constant negative or positive pressure (±0.2 in.) under the hood. A slight but constant vacuum on the order of −4.0 to −6.0 in. water was maintained in the analytical circuit when off-gas and reference air measurements were made.

The analytical circuit is depicted in Figure 2. A polarographic DO probe was used to measure oxygen partial pressure in the off-gas and reference air samples. Later, during the investigations, an electrochemical galvantic cell was used in series with the probe. Carbon dioxide was monitored batchwise by bleeding off gas flowing through the circuit to a volumetric CO_2 analyzer.

The gas was analyzed in this circuit by passing a small portion of the test gas through a flowmeter and past the oxygen probe. Gas temperature, humidity, and pressure were monitored and controlled within the circuit so that the difference in partial pressure of oxygen between the reference air and off-gas could be precisely obtained.

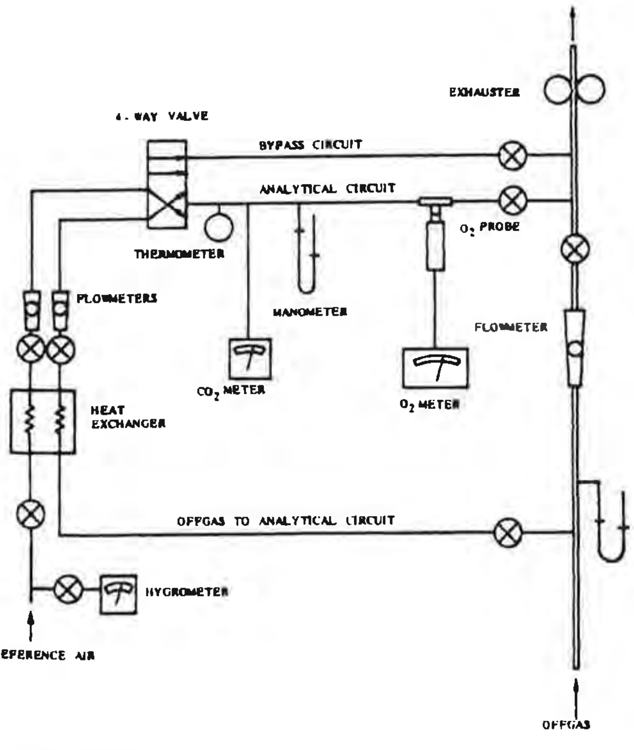


Figure 2—Schematic diagram of off-gas analyzer circuit.

CONDUCT OF THE TEST

Prior to the field test, the DO sensor was checked daily for accuracy with gases of certified composition. Pure nitrogen was also passed through the analytical circuit under test conditions to ensure that no leaks existed. These tests were normally conducted several times during the day.

The linearity of the probe was checked periodically by drawing the reference air past the sensor under various levels of reduced pressure while keeping the gas temperature constant. Under these circumstances the partial pressure of oxygen was directly proportional to the total absolute pressure. The criterion applied was that the ratio of absolute pressures for the two conditions divided by the ratio of the meter outputs fell in the range of 0.995 to 1.005.

Using this test for linearity, it was found that the calibration setting for probe output (in millivolts) was not critical, and essentially the same relative change in the voltage output occurred regardless of the setting with reference at ambient conditions. To obtain the maximum sensitivity, the reference output was set as close to full scale as was practical, because probe error is normally a fixed fraction of the full-scale reading. It should be emphasized that this procedure required precise measurement of the difference in the two gas streams and, therefore, it was not necessary to have an accurate determination of the absolute value of the partial pressure of oxygen in either stream.

Once the analytical circuit was checked, the gas collection hood was fixed in place at a predetermined location and a vacuum drawn at the instrument discharge. Reference air was first drawn into the analytical circuit and, a series of observations of temperature, humidity, pressure, and sensor millivolt readings were recorded over a period of about 5 minutes. A portion of the off-gas was diverted through the analytical circuit for a typical period of 5 to 10 minutes. During this time adjustments to the volume of off-gas drawn from the collection hood were made to obtain an equilibrium pressure condition beneath the hood at near ambient pressure (±0.2-in. water). Parallel measurements were recorded for off-gas temperature, humidity, pressure, CO_2 concentration, and sensor millivolt reading. Total off-gas flow rate was also recorded and used later in calculation of a bulk OTE for the entire tank volume. In addition to these measurements, mixed liquor temperature, DO, and local barometric pressure were also recorded. The hood was then moved to a new location and reference gas was again drawn through the circuit and measurements recorded. The reference gas check between each off-gas measurement provided a means for simple probe drift correction if required. This technique reduced errors in measuring the differences between off-gas and reference streams. The entire procedure for one determination required approximately 15 minutes.

The method involved sampling a sufficient number of locations within a given basin to obtain a representative sample of off-gas from the tank or tank element. A reasonable agreement between the applied and collected air flow rates was used to indicate a representative sampling layout. Initial field studies were conducted by drawing reference air directly from the plant air line. However, experience at a number of plants indicated that ambient air drawn directly within the vicinity of the analytical system yielded nearly identical readings to plant air. This approach greatly simplified the test procedure, and was adopted as a standard procedure thereafter.

The value of OTE for each sampling point was calculated using Equations 6, 7, 8, 9, and 10. Temperature corrections were made using the expression:

$$\mathrm{OTE}_{20^\circ} = \mathrm{OTE}_T \, 1.024^{(20-T)} \tag{11}$$

In order to estimate a weighted bulk average OTE for an entire tank or tank element, the following equation was used.

$$\mathrm{OTE}_w = \frac{\sum_{0}^{n} \mathrm{OTE}_n q_{an}}{\sum q_{an}} \tag{12}$$

where

OTE_w = weighted OTE
OTE_n = OTE value at sampling point, n, and
q_{an} = the collected gas flow rate per unit surface area at sampling point, n, (L^3/tL^2).

To provide comparisons between values of OTE measured for different systems, one may normalize the measured OTE by dividing it by $(C^* - C)$,

$$\mathrm{OTE}_{sp} = \frac{\mathrm{OTE}}{C^* - C} \tag{13}$$

In this equation, C^* is the calculated saturation value of oxygen in the wastewater. In diffused air systems C^* may be estimated by

$$C^* = C^*_{20} \frac{P_b}{P_s} \frac{C_{sT}}{C^*_{s20}} \beta \tag{14}$$

where

C^*_{20} = clean water saturation value in the same geometry at comparable air flow rate and at standard conditions (M/L^3),
P_b = atmospheric pressure during the test (f/L^2),
P_s = standard atmospheric pressure (usually 1.00 atm at 100% relative humidity (f/L^2),
C_{sT} = surface saturation book value for dissolved oxygen at the test temperature (M/L^3),
C^*_{s20} = the surface saturation book value for dissolved oxygen at 20°C (M/L^3), and
β = the ratio of process wastewater saturation value to that of clean water.

The value of C^*_{20} is often available from clean water tests of the diffuser system under the appropriate process configurations and gas flows. If it is not available it must be calculated using a gas-side correction model assuming some effective saturation depth.[2]

The data presented in this paper are uncorrected field measured OTE values except where subscripted as OTE_{20° or OTE_{sp}.

RESULTS

Off-gas field studies have been conducted during the past 3 years at over nine treatment facilities, including two industrial plants, and a variety of diffused air systems. Early tests were conducted at Whittier Narrows, California, Madison, Wisconsin, Brandon, Wisconsin, Ridgewood, New Jersey, and a DuPont facility. These tests were conducted in parallel with other field test procedures for comparative purposes. Other off-gas studies were conducted for a variety of purposes including:

- Evaluation of diffuser clogging problems,
- Evaluation of effectiveness of diffuser cleaning procedures,
- Evaluation of several diffuser types in side-by-side tests under process conditions, and
- Evaluation of aeration system control procedures.

Comparative test results. Table 2 presents the results of comparative tests conducted at four field sites. In general, the comparisons of the off-gas procedure with other currently-used field techniques are good. These tests reported were conducted under ideal conditions where the comparative test methods were applicable.

For example, field tests at Sites A and B were conducted at plants where mixed liquor DO values generally exceeded 0.5 mg/L and where approximate steady state conditions were achieved. Site A used both tapered aeration and step aeration thereby producing a wide variation in point values of OTE as measured by off-gas methods. Point values of steady state respirometeric tests versus off-gas data were, of course, not applicable, but overall bulk average values were comparable. At Site B, the small aeration tank was almost completely mixed with respect to DO. Point values of off-gas OTE varied substantially along test cross sections depending on off-gas flow rates (discussed later), but comparisons between tests were reasonable.

Results at Site C, another municipal plant, were also very favorable. At this plant, a non-steady state method with hydrogen peroxide was used for comparison. This

Table 2—Selected field test results off-gas versus other field methods.

		Off gas analyses				
Site	**Diffuser system**	**OTE-% (avg)**	**OTE-% (range)**	**DO-mg/L (range)**	**OTE-% (comparison test)**	**Comparison method**
A	Floor coverage ceramic	11.85	8.0–16.7	0.9–3.9	12.68	Respir. rate steady state
A	Dual roll coarse bubble	6.16	5.1–6.8	2.0–4.1	6.29	Respir. rate steady state
B	Jet aeration along longitud. wall (q = 67 L/s)	5.34	4.5–7.7	3.8[a]	5.31	Respir. rate steady state
	(q = 18 L/s)	9.58	8.7–11.1	1.1[a]	12.5	Respir. rate steady state
C	Spiral roll coarse bubble	3.2	—	1.8–4.1	3.3	H_2O_2/non-steady state
C	Spiral roll coarse bubble	1.1	—	6.8–7.2	1.7	H_2O_2/Non-steady state
D	Floor coverage coarse bubble	7.7	5.5–11.1	0	7.3–7.8[b]	Radioactive tracer

[a] Average DO in approximately CSTR system.

[b] Range of values depending on actual air flow rate.

[c] All OTE values calculated under field conditions and not corrected to 20°C.

method, described by Kayser,[5,21] must be performed under steady state conditions. Such conditions were established at Site C by diverting a substantial amount of the wastewater flow from the test system. Of special note, here, was the excellent agreement achieved between these two methods at an OTE value of 3.3%. The apparent poor agreement at the second test condition was not surprising considering the extremely low operating efficiency at that condition. The effectiveness of off-gas methods at low OTE values was of great concern to the investigators owing to the extremely small differences between reference air and off-gas oxygen concentrations. The excellent comparability of these methods at Site C was further reinforced by nonradioactive tracer tests performed at this site.

The tests conducted at Site D were reported by Campbell.[6] Here, the radioactive tracer technique using Krypton-85 and tritium was compared against the off-gas procedure. Excellent agreement was reported between the two methods in this highly loaded, single aeration tank where complete-mix conditions were approximated. The wide range of off-gas OTE point values measured at this facility was primarily the result of the variations in off-gas flow rates [3.4 to 4.5 L/m²/s (0.67 to 0.88 cfm/ft²)]. Even though the coarse bubble diffusers were distributed over the entire tank floor, there was a substantial localized boiling along the tank surface.

Important to note in all of these comparative tests, is the method of computation used to convert $\alpha K_L a$ values, which were estimated by all the other field test procedures, to OTE values measured by the off-gas procedure. The conversion was executed by the following general relationship,

$$\text{OTE} = \frac{\alpha K_L a(C^* - C)V}{q\rho} \qquad (15)$$

To achieve this comparison, it was necessary to have good estimates of C^* for the diffuser system geometry in the process wastewater at the appropriate temperature, pressure, and q, the gas flow rate of the diffuser system.

Other test results. The value of off-gas measurements goes far beyond the ability to estimate bulk OTE values for a given system. No other field test for oxygen transfer can provide discrete point information for a given system. The analysis of oxygen transfer at a specified location can greatly benefit the design engineer and the operator. A few examples of this information are presented to illustrate this extra benefit of the method.

Figure 3 presents the results of OTE and off-gas flow rate measurements that were observed at twelve cross-sections along the aeration tank at Site A. Floor coverage ceramic diffusers were used at this site. Tapered aeration was employed and primary effluent was discharged in equal amounts at three points along this folded tank. Tapered air was achieved in these tanks by varying diffuser density and, to some extent, by throttling gas flow rates to the diffuser headers. Aeration control was accomplished through DO monitoring and manual shut-down or start-up of blowers. Figure 3 indicates that during this period, DO control appeared to be effective. Because OTE for ceramic diffusers are relatively insensitive to air flow rates per diffuser, it seemed that increases in OTE along each tank section were the result of increases in alpha values.

A similar plot for the cross roll configuration at this same site appears as Figure 4. These folded tanks were equipped with fine bubble tubes in the first bay and coarse bubble units in the last two bays. All diffusers were uniformly spaced and primary effluent was evenly split to three points. This data suggests that gas flow rates were not well distributed, perhaps because of ineffective throttling of air control valves. The decline in OTE values along the tank length was not expected and could not be

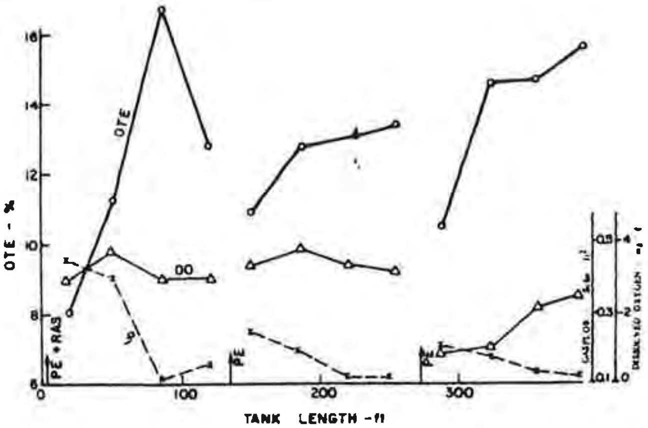


Figure 3—Gas transfer analyses along tank length—Site A. Floor coverage, ceramic domes, and tapered air.

entirely attributed to changes in gas flow rates. It is clear that operational corrections in this system were necessary.

An additional study was conducted near the discharge end of a three-pass cross roll system with various types of wide band tubular diffusers. A plan view of the tank indicating the header locations, diffuser locations and sampling plan is shown in Figure 5. The test results are presented in Table 3. Of particular interest was the apparent utility of the gas phase analysis which permits evaluation of several aerator types within a relatively small portion of a single tank. With tracers or liquid phase methods, such analysis is not possible.

The used units had been operating at the test plant for about 3 years. Comparing new and used Type C devices, there was a reduction in performance over that period. A similar reduction had most likely occurred with Type D diffusers, however, new Type D units were not available for test at that time.

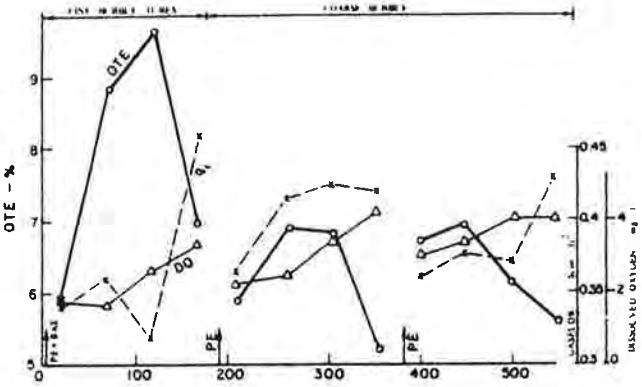


Figure 4—Gas transfer analyses along tank length—Site A. Cross roll, fine, and coarse bubble.

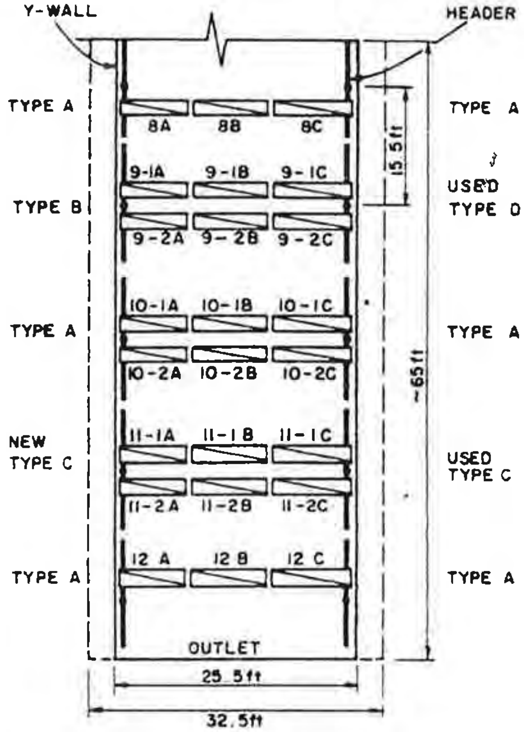


Figure 5—Aerator and sample site layout for comparative analysis of diffusers.

It should be noted that the discharge end of the basin was selected to minimize potential alpha variations in the test region. The diffuser layout was such that the reference system, Type A, was on both ends of the test zone to pick up the relative apparent change in alpha across the test boundary. The data substantiated a constant alpha for the test region. Based on the above results, this method can be a useful tool in aeration system retrofitting consideration. It can measure the dirty water performance characteristics of various systems at a particular site under actual field conditions, with modest expenditure of time and effort. However, these systems should not be com-

Table 3—In-process tubular diffusers comparisons with off gas procedures.

Diffuser	Location[a]	OTE-%[b]	DO-mg/L	OTE$_{20\text{-}0}$[c]
Type A	Station 8	7.95	0.9	8.29
Type B	Station 9	11.62	1.7	14.18
Used				
Type D	Station 9	9.17	1.7	11.33
Type A	Station 10	7.96	2.0	10.28
New				
Type C	Station 11	12.94	1.7	15.96
Used				
Type C	Station 11	9.05	1.7	11.00
Type A	Station 12	6.99	1.2	8.29

[a] See Figure 5.

[b] Field OTE.

[c] OTE corrected 20°C at 0 DO (Equations 11 and 13).

pared solely on the basis of OTE measurements when new, because other factors including back pressure, power, available driving force, and maintenance should also be considered.

Sample point selection in evaluating oxygen transfer data for a given system is critical to proper assessment of the system. Figure 6 presents a layout of the aeration tank at Site B that was equipped with jet aeration along one longitudinal wall directed across the tank. Although DO values were uniform in this small basin, off-gas flow rates and OTE values were not (Table 4). As would be expected, OTE values were generally higher over points of lower gas flow discharge. To estimate overall basin transfer efficiency using Equation 12, total captured gas flows were compared against measured values. Accordance between the two (±15%) indicates a reasonable sample point selection. In this particular study, gas capture flow rates were much higher than the rated capacity of the blowers. Further evaluation of the rating curves by the manufacturer revealed that the blower capacity had been seriously underestimated. No gas flow metering devices were available at Site B.

Table 4—Off gas analysis—Site B[a]

Station	q_A-L/m^2/s	OTE-%
1A	0.34	11.0
1B	0.80	9.3
2A	0.79	6.9
2B	0.75	8.8
3A	0.73	10.2
3B	0.40	11.1
Weighted Average	—	(9.58)
1A	2.21	4.5
1B	0.66	7.7
2A	2.27	4.9
2B	2.09	6.2
3A	2.61	4.4
3B	0.31	11.9
Weighted Average	—	(5.34)

[a] See Figure 6

DISCUSSION

The results of 3 years of field experience with the off-gas procedure have been very encouraging. The procedure is relatively simple and straightforward, and the equipment required for precise and accurate *in situ* measurement is available. Hood designs will continue to improve so that they are lighter and more portable than the ones used in this study.

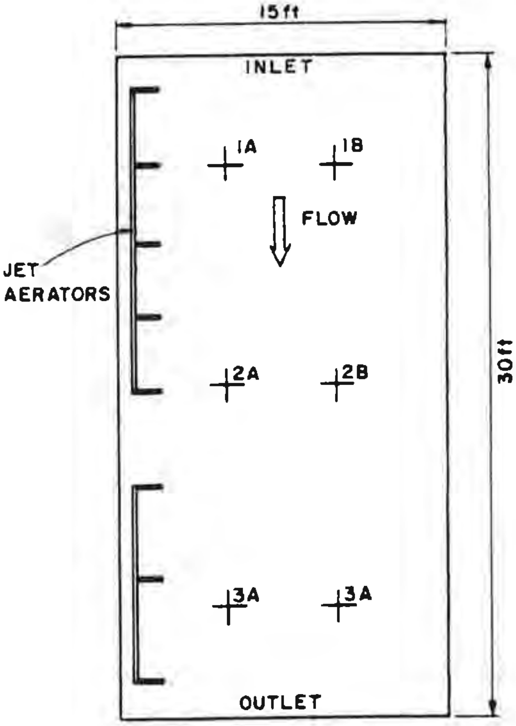


Figure 6—Aerator and sample site layout at Site B.

There is currently no way to effectively evaluate the precision of this method under process conditions because it is difficult to achieve constant performance of aeration equipment under field conditions. Under the most uniform aeration conditions, reproducibility seems to be well within acceptable ranges for this type of field measurement (less than ±10%). It should be noted that the estimate of the reproducibility of the method may be primarily the result of changing conditions at a given sampling point rather than the precision of the analytical system.

The accuracy of this technique cannot be determined because, to date, there is no standard against which to compare field OTE measurements. Many researchers feel that the radioactive tracer procedure described by Neal *et al.*[7] represents the state-of-the art available today for oxygen transfer rate measurement under process conditions. The results of the study at Site D were very encouraging in this regard. It should be remembered, however, that the tracer measurements provided a bulk average $\alpha K_L a$, whereas the off-gas measurements represented an average of local oxygen transfer efficiencies. It is also pertinent that where the objective of the test is to measure efficiency or predict air rate requirements, the off-gas method is significantly less subject to errors resulting from air rate measurement.

The accuracy of the off gas-measurement for prediction of local OTE is dependent on a number of measured variables including gas phase oxygen concentration, gas phase carbon dioxide concentration, gas phase humidity, gas phase temperature, gas phase pressure, and rate of off-gas flow. The accuracy of the oxygen sensor was continuously checked using certified gases or reduced pressure as described earlier. Results with the sensors used in this study were excellent, which indicates a high degree of precision and accuracy. Most sensors are temperature compensated. The effectiveness of this compensation varies, therefore each device should be carefully checked. Gas phase CO_2 and humidity seem to be the other major variables that influence computation of OTE. Off-gas flow rate measurement is used in Equation 12 primarily to weight OTE values. Its accuracy, therefore, is of secondary interest. On the other hand, if Equation 4 is used to estimate OTE values, a very accurate assessment of off-gas (and inlet gas) rates is required. Downing[13] employed CO_2 injection in the outlet gas with subsequent CO_2 analysis in the gas stream to ensure accurate estimates of gas flow. A sensitivity analysis of the parameters influencing the calculation of OTE will be published in the near future.

In evaluating the off-gas procedure against other methods currently available, several advantages and disadvantages may be enumerated. Some off-gas methods are particularly suitable because they:

- Measure local performance,
- Yield OTE directly and are relatively insensitive to the precision of air flow measurement,
- Are applicable in tanks where spatial variation of gas flow rate, loading, DO, and alpha exist,
- Seem to have exceptionally good precision and accuracy as compared to other conventional methods,
- Produce relatively fast and inexpensively,
- Provide a simple and reliable means of measuring alpha values in aeration systems of known clean water performance,
- Provide a means for simultaneous side-by-side comparisons of different aeration systems under process conditions,
- Are applicable in anoxic tanks, and
- Do not require process interruption.

Off-gas methods can be disadvantageous because:

- Technique is not applicable to mechanical aeration systems;
- Tanks must be accessible to personnel,
- Severe foaming may complicate gas sampling,
- Severe turbulence may cause difficulty in hood placement, and
- Method requires accurate measurements of CO_2 and humidity of reference air and off-gas.

Additional field research continues with the off-gas procedure. The method has a wide list of applications that extend beyond the routine measurement of bulk transfer efficiency. As indicated previously, off-gas provides air distribution and transfer efficiency profiles that can be used to evaluate system operation and maintenance requirements. Furthermore off-gas may be used to monitor temporal changes in oxygen transfer caused by diffuser clogging, alpha variations, and gas flow adjustments. Recently the off-gas method has been used to evaluate a variety of diffuser devices in side-by-side tests under process conditions.

The translation of clean water oxygen transfer data to process conditions continues to produce a significant amount of uncertainty in the design of aeration systems. Through the use of field measuring techniques, a compilation of useful data will eventually be accumulated to provide the design engineer with better scale-up data. Hopefully, the off-gas technique will provide an additional tool to achieve that end.

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APPENDIX I I

FIELD DATA SHEETS

PAGE: 1
DATE: Nov 14 2017
SITE: Santa Fe, NM
UNIT: North Aeration Basin

MLT: 20.4°C
BAROM: 24.00 in. Hg.
TDS:

Hood: 2'x8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1020	DAA				-8.0	1005			
1022	1.1	1-135				829		0.55	
1023	"	1-133				822		0.53	20.4° C
1024	"	1-133				826		0.56	
1025	1.1	1-133✓				829		0.55	
1026	DAA				-8.0	1009			
1031	DAA				-8.0	1007			
1034	1.2	1-90				820		0.59	
1035	"	1-93				814		0.56	20.4°C
1036	"	1-94				801		0.57	
1037	1.2	1-98✓				800		0.56	
1038	DAA				-8.0	1010			
1044	DAA				-8.0	1008			
1046	1.3	1-135				791		0.58	
1047	"	1-135				800		0.57	20.4°C
1048	"	1-133				799		0.57	
1049	1.3	1-133				795		0.61	
1050	DAA				-8.0	1014			
1058	DAA				-8.0	1007-8			
1100	1.4	1-88				828		0.39	
1101	"	1-75							20.4°C
	"	AIR OFF!							
	1.4								

PAGE: 2
DATE: NOV. 14, 2017
SITE: SANTA FE, NM
UNIT: NORTH BASIN

MLT: 20.4°C
BAROM: 24.00 IN. Hg
TDS:

HOOD: 2'×8'

		ROTA	ROTA						
TIME	STATION	NO MM/P	TEMP	PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1205	DAA				-8.0	1003		1.09	
1207	1.4	2-90				873		1.20	
1208	"	2-73				875		1.26	20.4°C
1209	"	2-73				882		1.25	
1210	1.4	2-80				877		1.24	
1211	"	2-80✓				879		1.30	
1212	DAA				-8.0	1001			
1219	DAA				-8.0	1003-4			
1221	1.5	1-230				884		1.69	
1222	"	2-60				873		1.76	20.4°C
1223	"	2-60				889		1.57	
1224	1.5	2-60				884		1.68	
1225	"	2-60✓				880		1.66	
1226	DAA				-8.0	1003			
1233	DAA				-8.0	1003-4			
1235	1.6	2-70				861		1.68	
1236	"	2-67				863		1.76	20.4°C
1237	"	2-62				852		1.65	
1238	1.6	1-230				874		1.64	
1239	"	1-235✓				860		1.77	
1240	DAA				-8.0	1003			
1246	DAA					1004			
1248	1.3	2-67				835		1.63	
1249	"	2-69				844		1.50	20.4°C
1250	"	2-58				833		1.64	
1251	1.3	2-65				850		1.51	
1252	"	2-65✓				841		1.64	
1253	DAA				-8.0	1002-3			

PAGE: 3
DATE: NOV. 14 2017
SITE: SANTA FE, NM
UNIT: NORTH BASIN

MLT: 20.4°C
BAROM: 24.00 IN. HG
TDS

HOOD: 2'x8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1303	DAA				-8.0	1002			AIRFLOW SO 1450
1305	1.2	1-250				845		135	AIRFLOW NO 1840
1306	"	1-250				845		1.24	
1307	"	1-250				846		1.41	20.4
1308	1.2	1-230				848		1.26	
1309	"	1-230				855		1.24	
1311	DAA				-8.0	1002			
1328	DAA				-8.0	1001			
1330	1.1	2-64				872		1.15	
1331	"	2-65				866		1.31	20.4°C
1332	"	2-66				874		1.04	
1333	1.1	2-58				873		1.30	
1334	"	2-58				870		1.18	
1335	DAA				-8.0	998			

PAGE: 4
DATE: NOV 14, 2017
SITE: SANTA FE, NM,
UNIT: SOUTH BASIN

MLT: 20.5°C
BAROM: 24.00 IN. Hg
TDS

HOOD: 2' x 8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1437	DAA				-8.0	1000-1			
1439	1.15	1-220				873		0.95	
1440	"	1-210				873		1.04	20.5°C
1441	"	1-210				870		1.08	160°F
1442	1.15	1-220				868		1.01	AIRFLOW SO 1620
1443	"	1-230				871		0.94	
1444	DAA				-8.0	1002			AIRFLOW NO 1870
1450	DAA				-8.0	1002			
1452	1.25	1-190				863		1.05	
1453	"	1-190				844		1.01	20.5°C
1454	"	1-190				858		0.98	
1455	1.25	1-200				845		0.91	
1456	"	1-200				855		0.95	
1457	DAA				-8.0	1001			
1502	DAA				-8.0	1000			
1504	1.35	1-235				855		1.03	
1505	"	1-215				836		1.05	20.5°C
1506	"	1-215				867		1.09	
1507	1.35	1-215				843		0.89	
1508	"	1-220 ✓				865		0.99	
1509	DAA				-8.0	999			
1514	DAA				-8.0	1001			
1516	1.45	1-235				878		1.04	
1517	"	1-235				874		0.97	20.5°C
1518	"	1-235				879		1.06	
1519	1.45	1-235				880		1.03	
1520	"	1-235				879		0.99	
1521	DAA				-8.0	1000			

PAGE: 5
DATE: NOV. 14, 2017
SITE: SANTA FE, NM
UNIT: SOUTH BASIN

MLT: 20.5°C
BAROM: 24.00 IN. HG
TDS:

Hood: 2.80'

TIME	STATION	ROTA	ROTA		CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
		NO MM/P	TEMP	PRESS					
1528	DAA				-8.0	1003			
1530	1.55	1-160				874		1.10	
1531	"	1-165	↑			873		0.89	20.5°C
1532	"	1-200				866		0.97	
1533	1.55	1-210				871		0.89	
1534	"	1-200 ✓				862		1.00	
1535	DAA				-8.0	1001			
1539	DAA				-8.0	1001			
1541	1.65	1-208				856		1.05	
1542	"	1-195				877		0.96	20.5°C
1543	"	1-195				886		1.03	
1544	1.65	1-195				878		0.96	
1545	"	1-195 ✓				878		1.06	
1546	DAA				-8.0	1002			

AMBIENT 61F DEW POINT - 23F RH - 22%
30.08 IN. HG BARO.

PAGE: 1
DATE: NOV. 15, 2017
SITE: SANTA FE, NM
UNIT: NORTH BASIN

MLT: 20.1°C
BAROM: 30.19-6.19 = 24.00 W.Ho
TDS:

Hood: 2'x8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	ROTA PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1026	DAA				-8.0	1005			
1028	3.1N	2-65				898		3.01	20.1°C
1029	"	2-64				903		2.87	
1030	"	2-50				902		2.90	
1031	3.1N	1-210				908		3.05	
1032	"	1-250				899		2.85	
1033	"	2-55				900		3.04	
1034	DAA				-8.0	1005			
1042	DAA				-8.0	1007			
1044	3.2N	2-70+				909		2.72	
1045	"	2-70				910		2.76	20.1°C
1046	"	2-68				909		2.70	
1047	3.2N	2-63				909		2.91	
1048	"	2-50				912		2.75	
1049	DAA				-8.0	1006			
1053	DAA				-8.0	1007			
1055	3.3N	2-69				908		2.75	
1056	"	2-71				910		2.76	20.1°C
1057	"	2-70				912		2.69	
1058	3.3N	2-60				914		2.71	
1059	"	2-60				910		2.77	
1100	DAA				-8.0	1007			
1113	DAA				-8.0	1005			
1115	3.4N	2-79				909		2.64	
1116	"	2-85				910		2.37	20.1°C
1117	"	2-73				906		2.55	
1118	3.4N	2-77				910		2.45	
1119	"	2-75✓				906		2.37	

1120 DAA -8.0 1005

PAGE: 2
DATE: NOV. 15, 2017
SITE:
UNIT: SANTA FE, NM
NORTH BASIN 2ND CHANNEL.

MLT: 20.1°C
BAROM: 30.19 - 6.19 = 24.00 IN. HG.
TDS:

HOOD: 2'x8'

scfm.

TIME	STATION	ROTA	ROTA		CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
		NO MM/P	TEMP	PRESS					
1138	DAA				-8.0	1603			AIRFLOW SO - 1620
1140	3.5N	2-70				901		2.57	AIRFLOW NO - 1930
1141	"	2-72				905		2.49	
1142	"	2-75				909		2.27	20.1°C
1143	3.5	2-74				901		2.30	
1144	"	2-74✓				909		2.45	
1145	DAA				-8.0	1006			
1149	DAA					1006			
1151	3.6N	2-59				908		2.71	
1152	"	2-63				898		2.54	20.1°C
1153	"	2-63				895		2.58	
1154	3.6N	2-58				904		2.54	
1155	"	2-58✓				901		2.69	
1156	DAA				-8.0	1007			
1158	DO	END OF GRID 1 = 1.50 MG/L							20.1°C
1203	DO	END OF GRID 2							
					→ 1.95-2.0 MG/L				20.1°C
1208	DO	WALKWAY CHANNEL			0.40 MG/L				20.1°C

PAGE: 3
DATE: NOV 15, 2017
SITE:
UNIT: SANTA FE NM.

MLT: 20.2° C
BAROM: 30.19 - 6.19 = 24.00 IN. Hg
TDS:

NORTH BASIN - GRID 1 HOOD: 2'x8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	ROTA PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1355	DAA				-8.0	1004			
1357	1.5N	2-65				887		1.81	20.2°C
1358	"	2-78				881		1.75	
1359	"	2-72				878		1.73	Airflow So 1630
1400	1.5N	2-62				887		1.77	Airflow No. 1920
1401	"	2-62✓				888		1.68	
1402	DAA				-8.0	1000			
1410	DAA				-8.0	1003			
1412	1.6N	2-62				849		1.56	
1413	"	2-62				869		1.62	20.2°C
1414	"	2-62				857		1.56	
1415	1.6N	2-62				861		1.63	
1416	"	2-64✓				857		1.56	
1417	DAA				-8.0	999-1000			
1423	DAA				-8.0	1003			
1425	1.4N	2-77				879		1.62	
1426	"	2-77				881		1.61	20.2°C
1427	"	2-76				878		1.68	
1428	1.4N	2-75				878		1.57	
1429	"	2-75✓				872		1.50	
1430	DAA					1000-1			
1434	DAA				-8.0	1001			
1436	1.3N	2-71				847		1.65	
1437	"	2-67				845		1.56	20.2°C
1438	"	2-67				843		1.64	
1439	1.3N	2-67				847		1.57	
1440	"	2-67✓				838		1.61	
1441	DAA				-8.0	998-999			

PAGE: 4
DATE: Nov 15, 2017
SITE:
UNIT: Santa Fe, NM
North Basin

MLT: 20.2°C
BAROM: 30.19 -6.19=24.00 in. Hg
TDS

Hood: 2'x8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1459	DAA				-8.0	1006-7			
1503	1.2N	2-65				853		1.43	
1504	"	2-54				855		1.61	20.2°C
1505	"	2-65				856		1.33	
1506	1.2N	2-64				843		1.29	
1507	"	2-58✓				851		1.49	
1508	DAA				-8.0	1007			
1511	DAA				-8.0	1007			
1513	1.1N	2-58				870		1.30	
1514	"	2-64				874		1.50	20.2°C
1515	"	2-64				871		1.48	
1516	1.1N	2-66				877		1.34	
1517	"	2-65✓				873		1.45	
1518	DAA				-8.0	1006			

PAGE: 1
DATE: Nov. 16, 2017
SITE: Santa Fe
UNIT.
North Basin - First Channel - Grid 2 Hood: 2' x 3'

MLT: 19.9°C
BAROM: 30.13-6.19=23.94 in. Hg
TDS

TIME	STATION	ROTA NO MM/P	ROTA TEMP	ROTA PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1036	DAA				-8.0	1001			
1038	2.1N	2-60				889		2.53	19.9°C
1039	"	2-66				884		2.56	
1040	"	2-65				886		2.59	
1041	2.1N	2-61				884		2.45	
1042	"	2-58✓				888		2.52	
1043	DAA				-8.0	1005			
1057	DAA				-8.0	1006			
1059	2.2N	2-66				892		2.58	
1100	"	2-66				895		2.47	19.9°C
1101	"	2-70				896		2.51	
1102	2.2N	2-70				890		2.44	
1103	"	2-72✓				892		2.50	
1104	DAA				-8.0	1009-10			
1111	DAA				-8.0	1005			
1113	2.3N	2-73				880		2.44	19.9°C
1114	"	2-80				878		2.54	
1115	"	2-78				880		2.51	
1116	2.3N	2-78				883		2.47	
1117	"	2-78✓				889		2.41	
1118	DAA				-8.0	1009			
1126	DAA				-8.0	1004			
1129	2.4N	2-70				887		2.37	
1130	"	2-75				878		2.50	19.9°C
1131	"	2-75				889		2.36	
1132	2.4N	2-74				874		2.38	
1133	"	2-76✓				880		2.37	
1134	DAA				-8.0	1005			

PAGE: 2
DATE: NOV. 16, 2017
SITE:
UNIT: SANTA FE, NM

MLT: 19.9°C
BAROM: 30.13 − 6.19 = 23.94 IN. HG.
TDS:

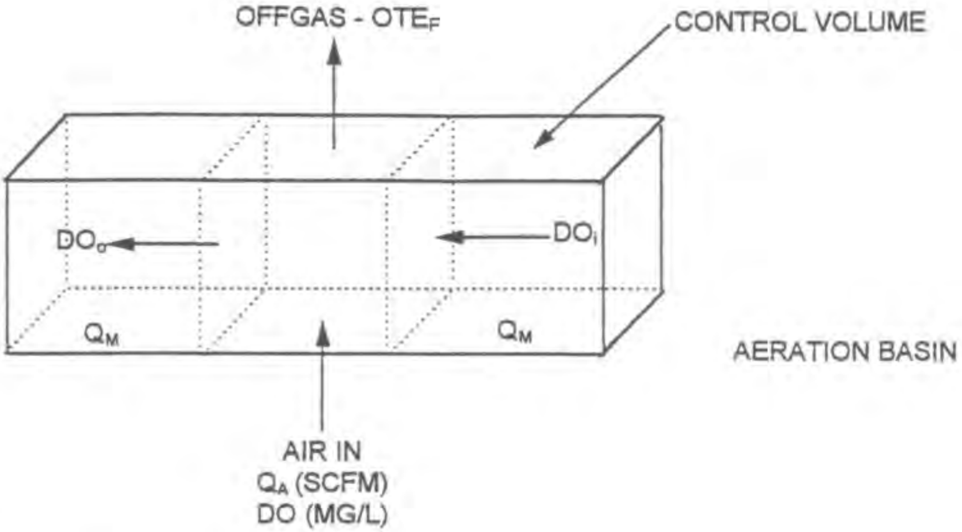
NORTH BASIN - ~~SECOND~~ FIRST CHANNEL - GRID 2   HOOD: 2'x8'

TIME	STATION	ROTA NO MM/P	ROTA TEMP	PRESS	CELL PRESSURE	DIGITAL OUTPUT	CELL TEMP	DO CONC	MISC DATA & COMMENTS
1149	DAA				-8.0	1005			
1151	2.5N	2-72				870		2.34	
1152	"	2-74				875		2.27	19.9°C
1153	"	2-74				878		2.19	
1154	2.5N	2-75				879		2.26	
1155	DAA				-8.0	1007			
1202	DAA					1003			
1204	2.6N	2-74				872		2.23	
1205	"	2-78				864		2.32	20.0°C
1206	"	2-78				874		2.37	
1207	2.6N	2-80				874		2.31	
1208	"	2-77 ✓				868		2.28	
1209	DAA				-8.0	1007			
1215	DO.	END	GRID	3	2.20MG/L		20°C		
1218	DO	END	GRID	1	1.35MG/L		20°C		
				AIRFLOW	→	SOUTH		1530	SCFM
				AIRFLOW	→	NORTH		1670	

APPENDIX III

MASS BALANCE PROCEDURE TO CALCULATE OXYGEN UPTAKE RATE

OUR BY GAS-PHASE MASS BALANCE



MASS BALANCE

$$\text{OUR} = \frac{\text{OTR} - \text{DO TRANSPORT}}{\text{VOLUME OF LIQUID IN CONTROL ZONE}} - \frac{\Delta \text{ DO CONCENTRATION}}{\text{TIME}}$$

WHERE:

OUR = OXYGEN UPTAKE RATE {MG/L/HR}

OTR = OXYGEN TRANSFER RATE {MG/HR}

= $Q_A (1.036)(OTE_F)(454{,}000)$

Q_A = AIR RATE TO CONTROL VOLUME IN SCFM

1.036 = LBS OF OXYGEN PER HOUR PER 1 SCFM

OTE_F = GAS PHASE OXYGEN TRANSFER EFFICIENCY UNDER PREVAILING CONDITIONS BY OFFGAS ANALYSIS LBS OXYGEN TRANSFERED/LBS OXYGEN SUPPLIED

454,000 = MG/LB

DO TRANSPORT = $(DO_{OUT} - DO_{IN})(Q_M)(60)(3.785)$ {MG/LHR}

Q_M = LIQUID FLOW RATE THROUGH CONTROL VOLUME IN GAL/MIN

3.785 = LITERS/GAL

VOLUME OF CONTROL ZONE = LITERS

$\frac{\Delta \text{ DO CONCENTRATION}}{\text{TIME}}$ = END OF OBSERVATION PERIO[illegible] BY OBSERVATION TIME IN HOURS. AT STEADY STATE CONDITIONS THIS TERM IS ZERO SINCE DO IS ZERO.

APPENDIX IV

AERATION PAPER BY CEMAGREF

OXYGEN TRANSFER UNDER PROCESS CONDITIONS IN AN OXIDATION DITCH EQUIPPED WITH FINE BUBBLE DIFFUSERS AND SLOW SPEED MIXERS

OXYGEN TRANSFER UNDER PROCESS CONDITIONS IN AN OXIDATION DITCH EQUIPPED WITH FINE BUBBLE DIFFUSERS AND SLOW SPEED MIXERS

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ABSTRACT

Offgas tests were conducted at Milly la Forêt wastewater treatment plant, a low loaded oxidation ditch equipped with fine bubble diffusers and two banana blade mixers. These experiments showed a heterogeneity in Standard Oxygen Transfer Efficiencies along the tank. This can be related to differences observed on air flow rate per grid of diffusers. From a practical point of view, this implies that the offgas sampling pattern may include Oxygen Transfer Efficiency measurements on each grid of diffusers. Moreover, improvement in oxygen transfer due to horizontal liquid velocity was observed. The degree of Oxygen Transfer Efficiency improvement was approximately 20 % for a velocity of 0.4 m/s, which is less compared to the observed 40 % enhancement in clean water under the same aeration and mixing conditions. Presence of surface active agents may explain this difference. Finally, estimated alpha values are in the range of 0.60 to 0.64 with the mixers on and 0.75 to 0.78 with the mixers off.

KEYWORDS

activated sludge, fine bubble, horizontal velocity, off gas method, alpha factor, extended aeration

INTRODUCTION

Over the last few years, France has seen a multiplication of diffuser aeration systems (synthetic micro perforated membranes) coupled with mixers. The dissociation of the aeration and mixing functions has several advantages : it enables an improvement in mixing (DUCHENE and HEDUIT, 1990) and a greater elimination of nitrogen (DUCHENE, 1989). Moreover, it increases the oxygen transfer efficiency : in clean water, an increase in the oxygen transfer capacity of 40% to 50% was observed in different oxidation ditches by implementing a horizontal velocity of 0.4 m/s, for a water depth in the range of 2.2 to 4.65 m (DERONZIER *et al*, 1996). Few studies have been made on the influence of the mixed liquor rotation on oxygen transfer under process conditions.

The purpose of this paper is to present the initial results obtained in the oxidation ditch of Milly la Forêt. The oxygen transfer efficiency was determined by the off gas method (REDMON and BOYLE, 1981, REDMON *et al.*, 1983, EWING *et al.*, 1988 BOYLE *et al.,* 1989), which enables measurements to be taken without disturbing the operation of the aeration tank. This paper relates to the application of the off gas method to the particular case of oxidation ditches, of which few details can be found in the literature. The influence of various factors (horizontal liquid velocity, air flow rate, diffuser layout) on the oxygen transfer is then examined.

METHODOLOGY

The measurements were performed in an oxidation ditch operating as an extended aeration system at Milly la Forêt (France). The oxidation ditch, illustrated in diagrammatic form in Figure 1, is equipped with 720 SANITAIRE 9' EPDM diffusers, supplied with air by a ROBUSCHI/RB 80 blower. Agitation is provided by two FLYGT type 4430 mixers, 2 m in diameter, mounted side by side. A variable frequency drive (10 - 50 Hz) was used to adjust the horizontal liquid velocity.

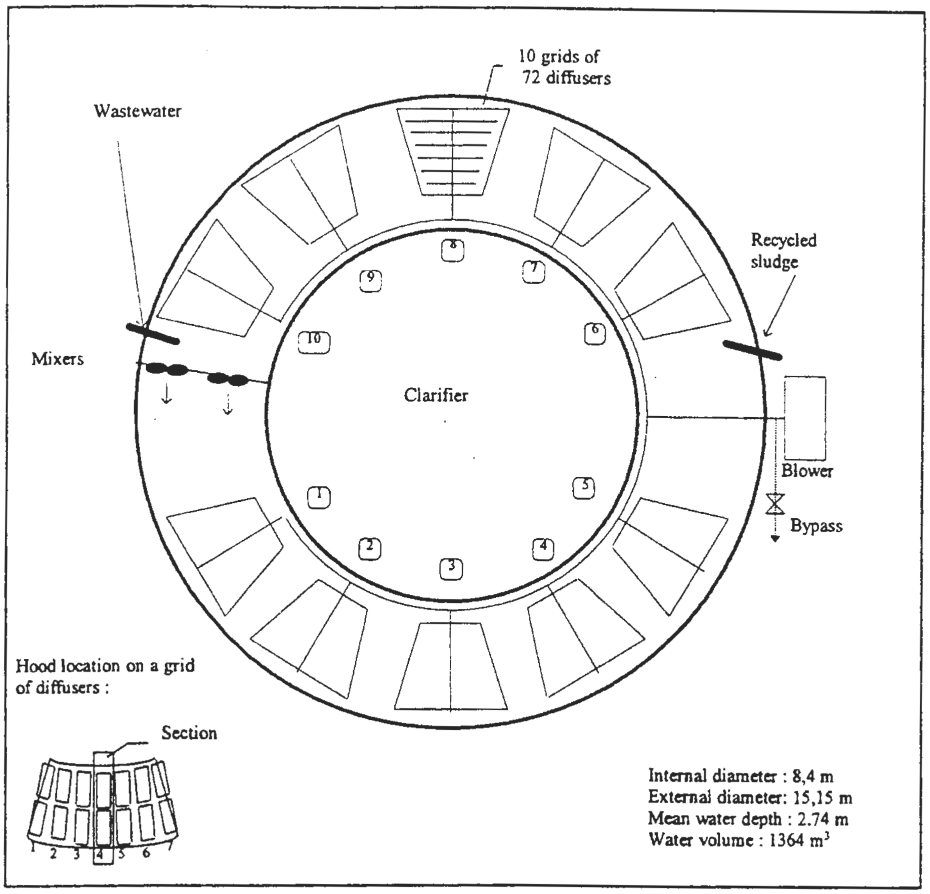

Figure 1. Milly la Forêt oxidation ditch

The velocity of the liquid (v) was determined using an OTT CE hydrometric propeller placed in one section of the ditch, away from all major perturbation. The measurements were recorded at 20 points, regularly distributed over the section, with the aeration stopped.

The air flow rate to the basin (q_e) was measured using an orifice plate. Results are expressed at 20 °C, 1013 hPa and divided by the number of diffusers to yield air flow rate per diffuser (m^3/h.dif.).

The Oxygen Transfer Efficiency (OTE) was measured from offgas analysis. Offgas was collected using a wood and polystyrene hood with a surface area of 2 m². The oxygen partial pressure of the gases, together with the offgas flow rate were determined by the EWING ENGINEERING MARK V analyzer, according to the procedure defined by REDMON *et al.* (1983). The dissolved oxygen concentration in the oxidation ditch was measured by 2 amperometric oxygen probes (YSI 57).

The Oxygen Transfer Efficiencies presented are expressed under standard conditions as Standard Oxygen Transfer Efficiencies (SOTEs), i.e. a dissolved oxygen concentration of 0 mg/L, a temperature of 20°C (or 10 °C), and a pressure of 1013 hPa.
The average Standard Oxygen Transfer Efficiency of a grid or of the aeration system was obtained by weighting the SOTE values by the offgas flow rates collected at each sampling point.

The first purpose of this work was, on the one hand, to study the variations in the Standard Oxygen Transfer Efficiency along a grid of diffusers, and on the other hand to determine the minimum number of gas sampling points and their location, to account for the average SOTE of the aeration system.

To reach these objectives, the variations in the Standard Oxygen Transfer Efficiency were studied :

- over one and the same grid, for different air flow rates :
  - with the 10 grids operating with mixers on ;
  - with the 10 grids operating with mixers off ;
  - with one grid out of two (1, 3, 5, 7 and 9) operating with mixers on ;
- over the entire oxidation ditch.

The influence of the horizontal flow velocity, of the air flow rate and of the diffuser layout on the oxygen transfer were then assessed for three configurations of the aeration system (see Figure 1) :

- configuration 1 : the 10 grids of 72 diffusers operating ;
- configuration 2 : one grid out of two operating (1, 3, 5, 7 and 9) ;
- configuration 3 : four consecutive grids operating (1,2, 3 and 4).

RESULTS AND DISCUSSION

1) Evolution of the Standard Oxygen Transfer Efficiency along a grid of diffusers

After verifying that the Standard Oxygen Transfer Efficiency was constant on one sampling point during the course of the test day, the SOTE was measured at different hood locations on a grid of diffusers (grid 2). Fourteen to sixteen sampling locations were required to collect all the offgas from the studied grid. Results are presented on Figures 2 to 4. Each point on the graphs represents a sampling point (2 per section, see sampling plan on Figure 1).

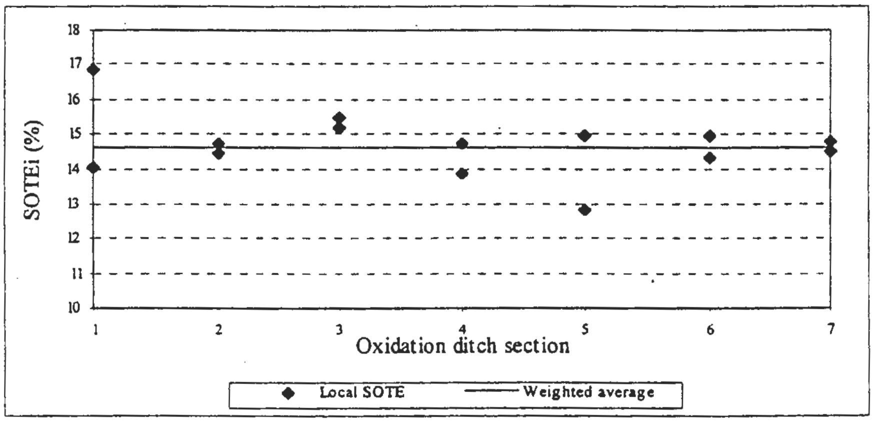

Figure 2. SOTE along grid 2 with all grids operating, v=0.33 m/s, q_e = 1.3 m^3/h.dif.

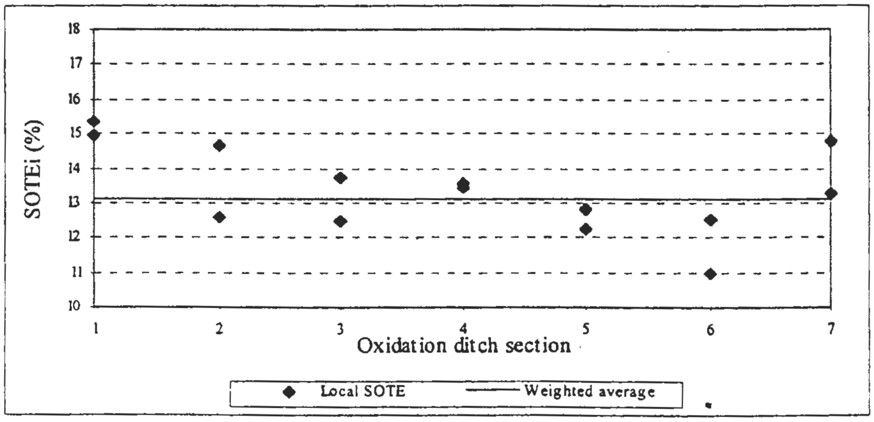

Figure 3. SOTE along grid 2 with all grids operating, v=0 m/s, q_e = 1.3 m^3/h.dif

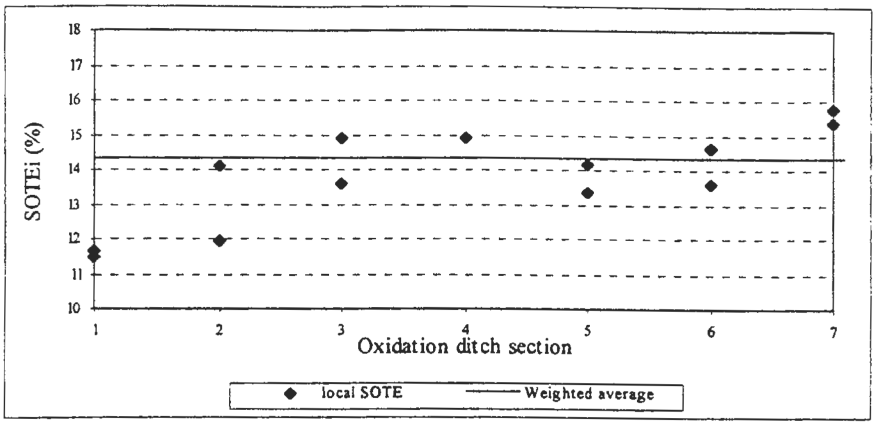

Figure 4. SOTE along grid 2 with 1 grid out of 2 operating, v=0.33 m/s, q_e = 2.2 m^3/h.dif.

When all the diffusers are in operation, in the presence of horizontal flow (Figure 2), the Standard Oxygen Transfer Efficiency is constant along a grid of diffusers. This is also the case with mixers off (see Figure 3), if the extreme points of the grid are excluded.

When one grid out of two is in operation (see Figure 4), the Standard Oxygen Transfer Efficiency increases in the direction of the current along the grid. It is, however, practically homogenous if the extreme points are excluded.

The number of sampling points required per grid of diffuser to obtain the average SOTE of the grid was determined in view of the results, taking initially 4 sampling points, on two symmetrical sections in relation to the center of the grid and excluding ends of the studied area : the differences between the average Standard Oxygen Transfer Efficiency obtained from 4 hood locations and the overall SOTE, determined from all the hood locations, are less than 3%.

These results obtained from measurements on grid 2 have been confirmed on grid 4.

2) Evolution of the Standard Oxygen Transfer Efficiency along the oxidation ditch

The Standard Oxygen Transfer Efficiency of the whole aeration system was determined from 4 hood locations per grid. Figure 5 presents weighted average SOTE values and air flow rates collected (q_s) on each grid.

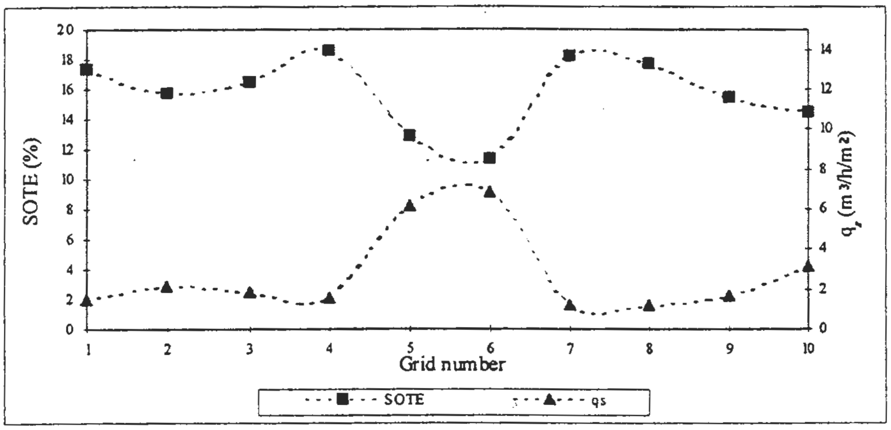

Figure 5. SOTE variation along the oxidation ditch, 10 grids operating ; v = 0.33 m/s; q_e = 1.3 m^3/h.dif.

The SOTE is not homogenous along the ditch. It depends on the air flow rate collected at each grid. The lower the air flow rate, the higher the Standard Oxygen Transfer Efficiency. For two identical air flow rates collected, the SOTE is the same. The weighted average SOTE corresponding to the entire aeration system is of 14.5 %.

3) Statistical influence of the number of grids investigated and of the number of sampling points per grid on the SOTE determination

Starting from the experimental data set consisting of 4 air flow rate/SOTE values per each grid (40 data), the weighted average ($SOTE_{wa}$) values of the aeration system were determined from random draws with replacement.

In the first case, $SOTE_{wa}$ was determined from a sample of 2 points (air flow rate and SOTE values) drawn on all the ten grids (20 draws with replacement). In the second case, $SOTE_{wa}$ was determined from a sample of 4 points (air flow rate and SOTE values) drawn on 5 grids previously determined from a random draw (20 draws with replacement).

Figure 6 presents histograms obtained from 500 draws in each case.

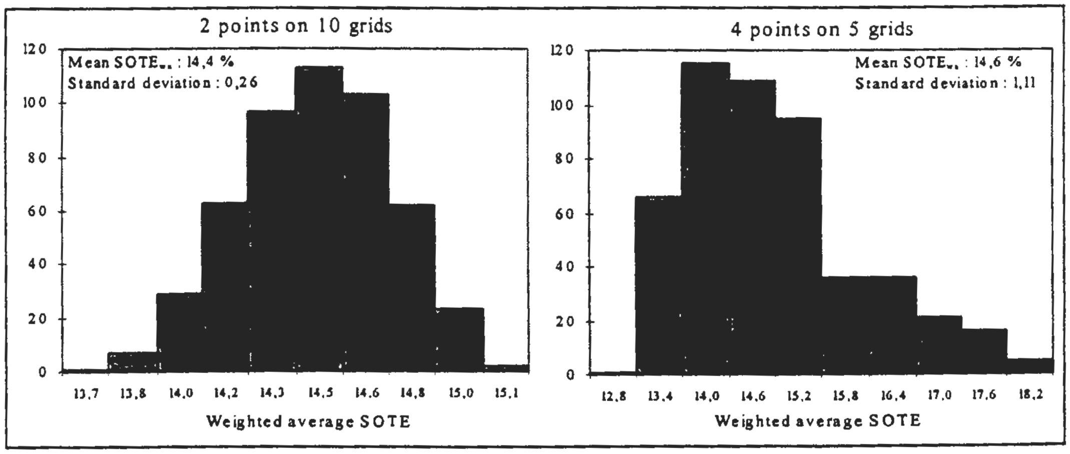

Figure 6. $SOTE_{wa}$ distribution in relation to sampling points

The confidence interval of 90% obtained from a random draw with replacement of 2 sampling points on 10 grids corresponds to a statistical accuracy (ratio of the difference of $SOTE_{wa}$ values limiting the confidence interval over the mean $SOTE_{wa}$ of the sample) of 5.9 %, whereas that obtained from a draw of 4 points on 5 grids corresponds to an accuracy of 25.5%

For an identical number of SOTE measurements, it is more advisable to sample each grid of diffusers, to take account of the heterogeneity of the oxygen transfer efficiencies along the ditch.

The distribution of the $SOTE_{wa}$ values obtained from a random draw with replacement of one, two, three or four sampling points per grid proves that the accuracy increases with the number of sampling points per grid. For a confidence interval of 90%, it is 8.4 %, 5.9 %, 4.9%, and 4.6% when 1, 2, 3 or 4 points per grid are taken. The statistical accuracy corresponding to 3 or 4 sampling points per grid are sufficient to determine the average Standard Oxygen Transfer Efficiency of the aeration system. Three sampling points correspond to 15% of the aerated area.

4) Influence of the horizontal flow, of the air flow rate and the diffusers layout on oxygen transfer

Figure 7 presents SOTE variations as horizontal velocity was increased from 0 to 0.45 m/s. Clean water measurements, previously performed according to non steady state clean water tests (DA-SILVA DERONZIER, 1994), are also reported on this graph.

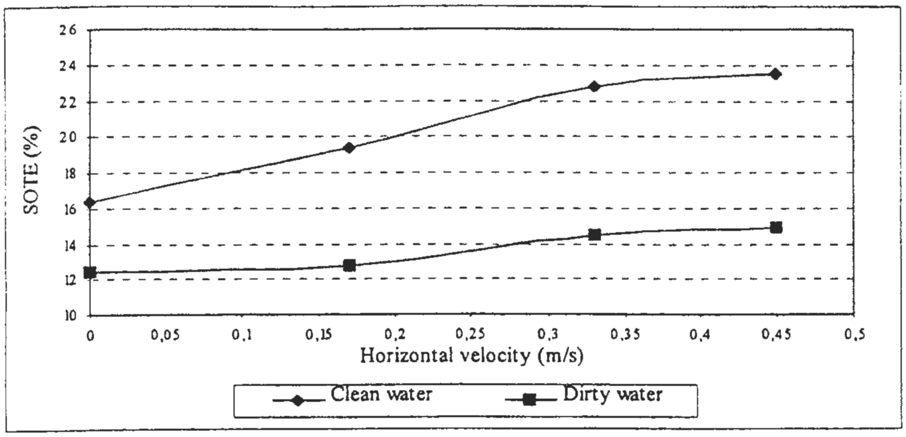

Figure 7. SOTE versus horizontal velocity, configuration 1, qe = 1.33 m^3/h.dif.

Oxygen transfer improvement due to a horizontal velocity of 0.45 m/s is of approximately 43 % in clean water and of 21 % under process conditions.

The influence of the number and the layout of the diffusers in operation and of the air flow rate per diffuser on the oxygen transfer is assessed by determining the alpha factor (See Table 1). The Standard Oxygen Transfer Efficiency under process conditions is compared to the clean water results.

Configuration	Air flow rate per diffuser (m^3/h)	Horizontal flow (m/s)	Alpha factor
1	1.3	0	0.75
1	1.3	0.17	0.63
1	1.3	0.33	0.61
1	1.3	0.46	0.62
2	2.2	0	0.78
2	2.2	0.33	0.64
3	3.4	0.33	0.61
3	4.5	0.33	0.60

Table 1. Alpha factor values determined at Milly la Forêt oxidation ditch

Alpha factor values are in the range of 0.75 to 0.78 when mixers are off. For a horizontal flow between 0.17 and 0.46 m/s, the alpha value is between 0.60 and 0.64, whatever the number of diffusers in operation and their layout, in the field of study concerned (immersion depth of the diffusers of 2.49 m, with an air flow rate per diffuser between 1.3 and 4.5 m3/h).

Such a decrease in the alpha factor, as a horizontal velocity is applied, may be induced by the presence of surface active agents.

In clean water, two mechanisms has been proposed to mainly explain oxygen transfer improvement with horizontal flow (DA SILVA-DERONZIER, 1994) :

- the specific interfacial area is enhanced by production of smaller bubbles, due to a shearing effect of the horizontal velocity on the nascent bubble ;
- horizontal velocity reduces the negative effect of spiral flows (increasing the upward velocity of the bubbles).

Both mechanisms yield to an enhancement of the air content and hence of the bubble residence time in the liquid.

Under process conditions, surface active agents, accumulated at the surface of gas bubbles, tend to make them smaller and more rigid, resulting in oxygen transfer decrease (STENSTROM and HWANG, 1979 ; HWANG and STENSTROM, 1985 ; BISCHOF *et al.*, 1993 ; WAGNER and POPEL, 1996). As a horizontal velocity is applied, several suppositions can be formulated :

- reduction of bubble size is lower compared to that in clean water, as it is already diminished by the effect of surface active agents ;
- bubble ascent is longer compared to no velocity. Surfactants have hence more time to be concentrated at the surface of gas bubbles, reducing oxygen transfer coefficient (K_L) ;
- threshold corresponding to the maximum oxygen transfer is reached for a lower horizontal velocity in dirty water than in clean water.

These remarks show that there is a need for further research work to better assess the influence of horizontal velocity on oxygen transfer.

CONCLUSIONS

The application of the off gas method to an oxidation ditch equipped with fine bubble diffusers and slow-speed mixers showed that :

- when all the diffusers are in operation, the Standard Oxygen Transfer Efficiency along a grid of diffusers is homogenous in the presence of an horizontal flow. Without horizontal flow, the SOTE is also homogenous except on the extremities of the grid.

- when the diffuser grids are spaced out (with one out of two operating), SOTE increases in the direction of the current in the presence of a horizontal flow.

- It may be necessary to sample each grid of diffusers, to take account of the heterogeneity of the Oxygen Transfer Efficiencies along the ditch. Two grids receiving the same air flow rate show identical efficiencies if they are symmetrically arranged in relation to the inlets of wastewater and recycled sludge, so initial measurements of the air flow supplied per grid would make it possible to minimize the number of grids to investigate.

- The statistical accuracy of the SOTE increases as the number of sampling points per grid of diffuser increases. At Milly la Forêt, three sampling points per grid are sufficient to determine the mean weighted Standard Oxygen Transfer Efficiency of the aeration system. This represents 15% of the aerated area.

- A horizontal velocity of approximately 0.4 m/s induce an oxygen transfer enhancement compared to no velocity. Under process conditions, the observed improvement is on the order of 20 %, substantially below the 40 % increase measured in clean water.

- The alpha factor determined when mixers are off is in the range of 0.75 to 0.78.

- With horizontal velocity, the alpha factor determined for different configurations of the aeration system reached 0.60 to 0.64 under process conditions. This value is independent of the number of diffusers in operation, of their layout and of the air flow per diffuser.
- These results are site specific and have to be confirmed on other aeration ditches.

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