Las Virgenes Municipal Water District

Tapia WRF – Process Air Evaluation

Technical Memorandum No. 1

Minimizing Air Usage at the Tapia WRF

FINAL
November 2011

Engineers...Working Wonders With Water™

LAS VIRGINES MUNICIPAL WATER DISTRICT

Tapia WRF – Process Air Evaluation

TECHNICAL MEMORANDUM
NO. 1

TABLE OF CONTENTS

Page No.

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

MINIMIZING AIR USAGE AT THE TAPIA WRF

1.0 EXECUTIVE SUMMARY

Current air usage at the Tapia Water Reclamation Facility (WRF) was evaluated based on a review of historical operating data, observations during plant site visits, theoretical air demand modeling, and aeration basin off-gas testing. The evaluation indicates excessive air usage at the aeration basins due to poor oxygen transfer efficiencies associated with the existing spiral-roll diffuser configuration and the location of dissolved oxygen (DO) probes within these basins. Our analysis shows that the aeration basins at the Tapia WRF consume between 70 and 94 percent more air per unit of plant influent flow (SCFM/mgd) than basins at similar plants treating to similar effluent requirements. We recommend that the District replace the existing spiral-roll diffuser system with a full-floor system. In addition to providing poor oxygen transfer efficiencies within the aeration basins, the existing swing arms are no longer manufactured by the original manufacturer (WSG & Solutions). Any repairs must be made by the District (in house) and replacement parts must be special ordered for manufacture.

The results of this evaluation indicate that a diffuser system upgrade will reduce current average air demands in the aeration basins by roughly 69 percent - from 10,000 to 3,100 SCFM. Preliminary planning-level construction costs associated with this upgrade are approximately $1.38 million. Based on current energy rates charged by Southern California Edison (SCE), the annual cost savings are expected to be approximately $115,000.

The air conveyance system at the Tapia WRF is leaking substantial amounts of air via numerous small to medium leaks both above and below ground. The leak survey performed by Carollo Engineers as part of this evaluation indicates an estimated leakage rate of approximately 500 SCFM from aboveground piping. Repairs to these leaks would cost approximately $6,000 to implement and would provide an estimated annual energy cost savings of $13,800.

The existing channel aeration system has reached the end of its useful life and does not represent an efficient use of process air for mixing within the channels. It is expected that the replacement of the existing channel aeration system with a new conventional spiral-roll system will increase the air usage within the channels by approximately 29 percent (from 2,100 to 2,700 SCFM) but the resulting improvement in mixing within the channels will represent a more efficient use of process air. Alternatively, process air demands within the channels may be eliminated through the incorporation of a large-bubble (proprietary) or pumped-mix channel mixing system. A pumped-mix channel mixing system is expected to cost approximately $428,000 and will save an estimated $57,900 in annual energy costs.

.

A financial summary of the improvements discussed within this memorandum is presented in Table 1.1. In this table, lifecycle ownership cost savings for each improvement are relative to estimated current operation and maintenance costs.

Table 1.1 Financial Summary of Improvements
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Improvement	Annual Energy Savings ($/Yr)	Preliminary Planning-Level Construction Costs ($)	20-Year Lifecycle Cost Savings[(1)] ($)
Aeration Basin Diffusers	115,000	1,376,000[(2)]	77,400[(3)]
Re-aeration Basin Diffusers	5,700	474,000	(441,000)
Channel Mixing[(4)]	(15,500)	400,000	(577,600)
Leak Repairs	13,800	6,000	168,000
Total	119,000	2,256,000	(773,200)

Notes:

(1) Lifecycle cost savings are compared against existing equipment and are based on a 6% discount rate. Lifecycle costs savings are shown as present worth.
(2) Energy efficiency rebates from SCE are expected to reduce the capital costs associated with the replacement of the aeration basin diffusers by up to $138,000.
(3) Assumes a maximum SCE energy efficiency rebate amount of $138,000 toward the replacement of the aeration basin diffusers.
(4) Based on installation of a new conventional spiral-roll channel mixing system.

With the exception of channel mixing, all of the improvements provide an annual energy savings. The aeration basin diffuser improvements show a simple payback period of 11.9 years. The RAS re-aeration basin improvements do not result in a significant energy savings by themselves, but will be required to facilitate the treatment of design plant influent flows (12 mgd). It is expected that this improvement may be deferred until the plant influent flows reach approximately 11 MGD. This is expected to occur around project year 15 (calendar year 2027).

Energy efficiency rebates from SCE (Southern California Edison) are expected to reduce the capital cost associated with the replacement of the diffuser system in the aeration basins by up to $138,000. The reduced capital costs would result in a lifecycle costs savings of approximately $77,400 over the existing spiral-roll diffuser system.

The channel mixing improvement (assuming a new conventional spiral-roll system) does not provide an annual energy savings but does represent a more efficient use of process air due to improved mixing within the channels. If the large-bubble or pumped-mix channel mixing systems were installed, a net annual energy savings would be achieved with a corresponding 20-year lifecycle cost savings.

The air flow reductions presented in this technical memorandum will be used as a basis for the blower evaluation – the next stage of the process air evaluation.

2.0 BACKGROUND AND PURPOSE

The operation of the process air system at the Tapia Water Reclamation Facility (WRF) represents a large percentage of the plant's overall energy consumption. Based on a review of energy billing data provided by Southern California Edison (SCE), energy usage at the Tapia WRF corresponds to a current annual cost of $1.2 million[1]. Historical blower flow and discharge pressure data indicate that operation of the blowers translates to an annual cost of approximately $345,000, or 30% of the facility's total annual energy costs.

Reductions in air flows and blower discharge pressures, and improvements in blower wire-to-air efficiencies will result in substantive energy cost savings.

Process air at the Tapia WRF is currently used at the following locations:

- Aerated grit chambers
- Process channels
    - Grit chamber effluent channel
    - Primary clarifier feed channel
    - Aeration basin feed channels
    - Mixed liquor channel
    - Return activated sludge (RAS) channel.
- Aeration basins
- RAS re-aeration basins
- Plant effluent filters (backwash air scour)

In addition to the consumption of air for the useful purposes listed above, a significant volume of air is leaking from the aging air conveyance system. This leakage contributes to the overall air demand at the Tapia WRF without adding any tangible benefit to the District.

The purpose of this Technical Memorandum is to characterize current process air demands at the Tapia WRF and define improvements that will minimize current and future process air demands. The engineering analysis within this technical memorandum will form the basis for the blower evaluation – the second phase of the process air evaluation.

---

[1] Based on an average annual energy rate of $0.0845\kWh charged by Southern California Edison (SCE) during 2010.

3.0 SUMMARY OF CURRENT AIR USAGE

Current process air demands at the Tapia WRF are summarized in Table 3.1. The air demands shown in Table 3.1 are categorized by diurnal minimum, annual average, and diurnal maximum values at each point of use.

Table 3.1 Current Process Air Demands
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

	Current Air Demands (SCFM)		
Point of Use	**Minimum**	**Annual Average**	**Maximum**
Grit Chambers	150	150	300
Channel Mixing(1)	2,100	2,100	2,100
Aeration Basins(2)	4,000	10,000	15,000
RAS Re-aeration Basins(3)	1,200	1,200	1,200
Effluent Filter Backwash Scour(4)	0	0	300
Conveyance System Leakage(5)	1,000	1,000	1,000
Total	8,450	14,450	20,200

Notes:
(1) Channel air flows are currently un-metered. Estimates of current channel air flows are based on comparisons of blower flows before and after closure of channel air isolation valves.
(2) Aeration basin flows based on off-gas testing and a review of operating data gathered from September, 2010 and January, 2011.
(3) Based on current air flows of approximately 600 SCFM to each basin (constant).
(4) Intermittent air usage. Each of twelve plant effluent filters are backwashed an average of once per day. Air scour lasts approximately 5 minutes per filter backwash cycle.
(5) Leak testing of aboveground air piping indicated total leakage of approximately 500 SCFM. Leakage from buried piping assumed to be of comparable magnitude.

The process air demands presented in Table 3.1 were determined by the following methods:

- Review of historical air flow data available from the plant SCADA database (aeration basin air flows)
- Off-gas testing (aeration basin air flows)
- Discussions with plant operations (filter scouring, and RAS re-aeration air flows)
- Observations during site visits (leak testing, and channel mixing air flows)
- Review of plant record drawings/design criteria (grit chamber air flows)

The engineering analysis used to determine current air flows at each point of use and methods to reduce these air flows are provided in the following section.

4.0 ENGINEERING ANALYSIS

4.1 Aeration Basins

The aeration basins represent the largest (almost 70 percent of average) process air demand at the Tapia WRF. A sizeable reduction in air usage within the aeration basins will result in significant energy savings.

The methods used by the project team to determine current aeration basin air flows will be discussed in detail in the following subsection (Section 4.1.1). The aeration basin air flows at the Tapia WRF were compared to those observed at two similar facilities:

- Plant A is a large 80 mgd plant that uses a Modified Ludzack-Ettinger (MLE) process. Plant A incorporates anaerobic digestion and side stream treatment to minimize return nitrogen loads. As a result, there is little ammonia-nitrogen load exerted by return streams within the main aeration basins.
- Plant B is a smaller 3.8 mgd plant that incorporates a step-feed nitrification-denitrification process. Plant B uses a pond system for solids treatment, which results in relatively low decant ammonia-nitrogen concentrations. Similar to Plant A, returns streams contribute little to oxygen demand in the main aeration basins.

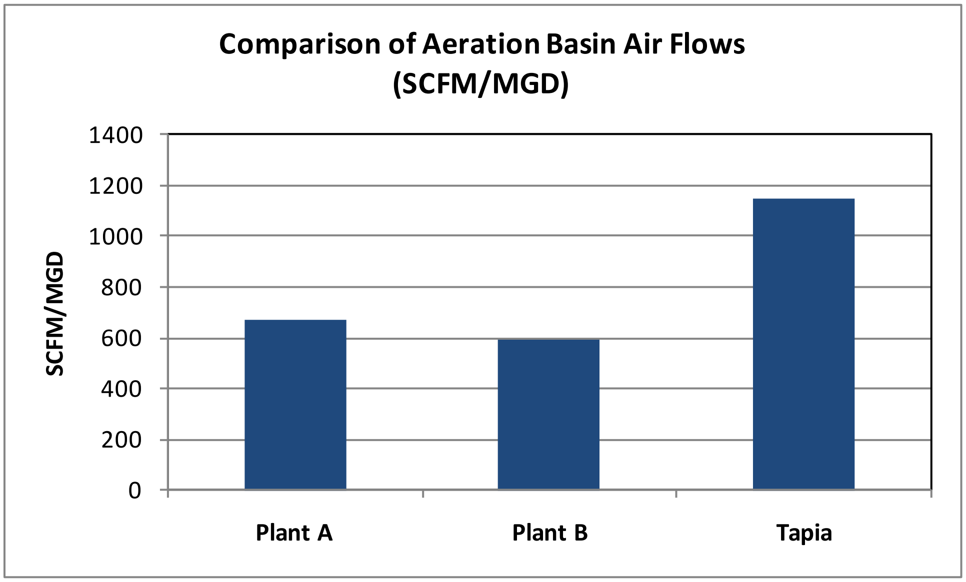


Figure 4.1 Comparison of Plant Performance - Aeration Basin Air Flows

The bar graph presented in Figure 4.1 suggests an opportunity to significantly reduce air usage within the aeration basins at the Tapia WRF. The aeration basins at the Tapia WRF consume between 70 and 94 percent more air per unit of plant influent flow (SCFM/mgd) than plants A and B. Similar to plants A and B, the solids handling processes incorporated by the Tapia WRF minimize the contribution to the aeration basin oxygen demand created by ammonia-nitrogen in plant return streams.

It should be noted that the previous comparison is limited by additional factors that may affect oxygen demand and Oxygen Transfer Efficiency (OTE), both of which directly influence the air flow demands presented in Figure 4.1. Impacts to air flows notwithstanding, these factors alone would not explain the large difference in aeration basin air flows between the Tapia WRF and plants A and B.

A schematic of the existing aeration basin diffuser system is presented in Figure 4.2. The schematic provided in Figure 4.2 represents the western half of a symmetrical six-basin, dual-serpentine aeration basin configuration. Air is delivered to the basins through fine bubble diffusers installed on swing-arm riser assemblies (eight assemblies per basin) located on one side of each basin. The swing-arm riser assemblies facilitate diffuser maintenance/replacement while a basin is in service.

The asymmetric delivery of air (air flows delivered at one side of basin) results in a liquid spiral-roll pattern within the basins. The liquid spiral-roll pattern was preferred in early designs as a method to improve mixing. As will be discussed in this memorandum, a liquid spiral-roll pattern is now considered inefficient aeration basin design.

The existing aeration basins are divided into several aeration zones (refer to Figure 4.2). Zones 1A and 2A are aerobic and account for all of the air consumed within the basins during normal operation. Normally anoxic Zones 1B and 2B are considered “swing zones” that may be operated aerobically as circumstances require. Zone 3 consists of an entire aeration basin (the influent zone of a dual-serpentine flow pattern) and is normally anoxic.

Zones 1B, 2B, and 3 are equipped with floating anoxic mixers that were provided as part of recent biological nutrient reduction modifications (2003 and 2009). As a plant reliability measure, submersible mixed liquor recycle pumps were installed within the basins to facilitate parallel operation.

As will be discussed in further detail, the existing aeration basin swing-arm diffuser system at the Tapia WRF adversely affects oxygen transfer efficiency (OTE). Substandard OTE results in excessive air usage within the aeration basins.

In addition to providing poor oxygen transfer efficiencies within the aeration basins, the existing swing arms are no longer manufactured by the original manufacturer (WSG & Solutions). Any repairs must be made by the District (in house) and replacement parts must be special ordered for manufacture.

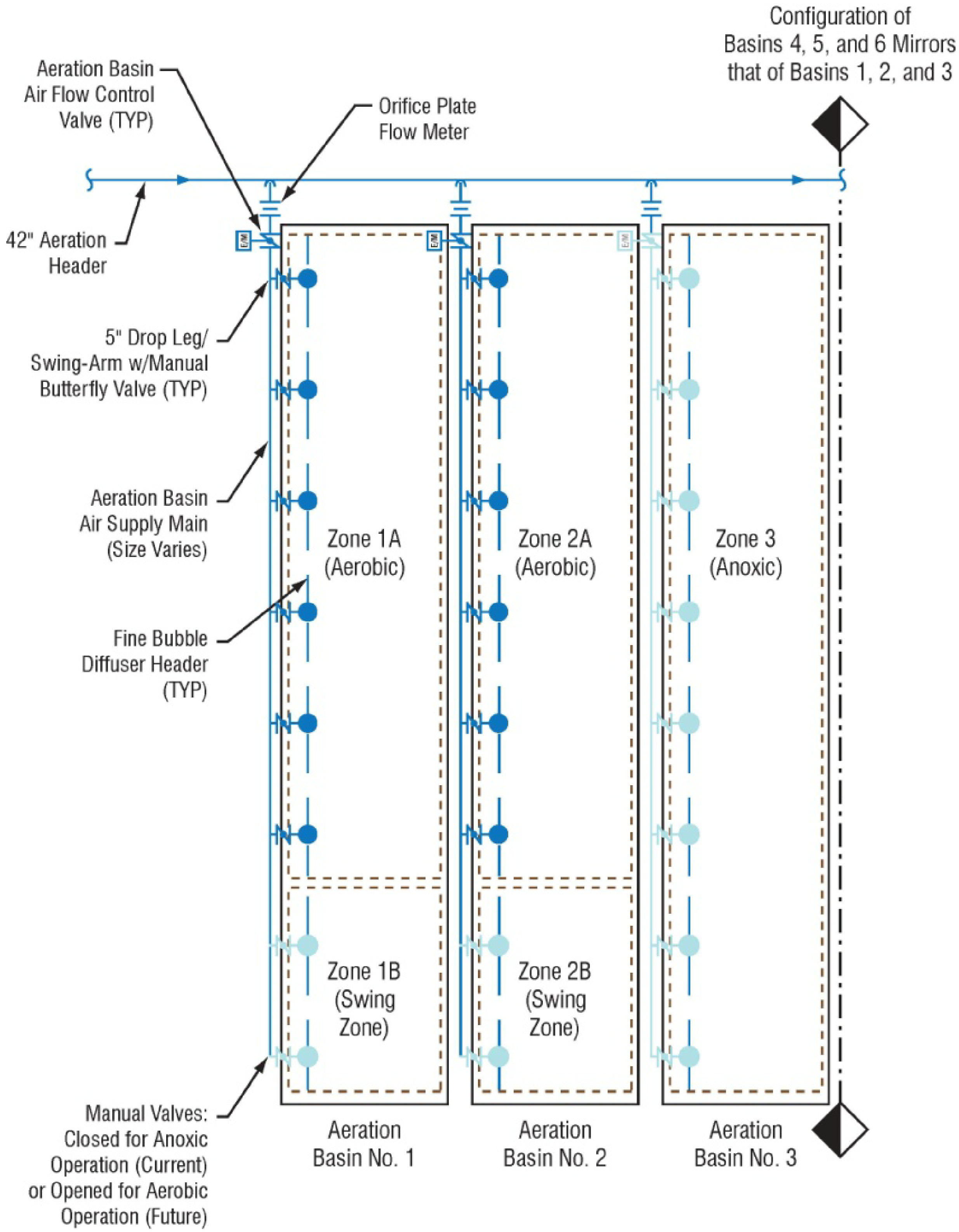


Figure 4.2 Existing Aeration Basin Swing-Arm Diffuser System

4.1.1 Current Air Use

Current air usage within aeration basins at the Tapia WRF was determined using the following methods:

1. Off-gas testing was performed by Dr. Stenstrom of UCLA to determine Oxygen Transfer Efficiency (OTE) within the aeration basins.
2. Aeration basin air flow data was collected from the plant SCADA system.

The off-gas test report is included for reference as Appendix A to this memorandum. As discussed within the off-gas report, OTE represents the percentage of oxygen introduced into an aeration basin that is actually transferred into the mixed liquor. Off-gas testing is commonly performed to determine OTE at wastewater treatment plants. The following equation defines OTE, as determined by off-gas testing:

It is useful to divide the analysis of OTE into two separate components:

- Determination of Standard Oxygen Transfer Efficiency (SOTE), also known as the “clean water” transfer efficiency. This is the value of oxygen transfer efficiency commonly published by aeration equipment suppliers.
- Conversion of SOTE to OTE to correct for actual process conditions. It is OTE that directly influences aeration basin air usage.

In a diffused aeration system, SOTE is influenced primarily by the size of the air bubbles produced by the diffusers. Small bubbles result in a greater surface area (per unit volume of air) than can be produced by large bubbles. Small bubbles also rise slowly through the liquid, providing more time for oxygen transfer. Consequently, smaller bubbles are associated with a higher SOTE. The goal of fine bubble diffuser systems is to minimize bubble size.

SOTE is a function of three parameters:

- Diffuser submergence depth
- Air flux
- Diffuser density

The greater the depth from which an air bubble is released, the longer it will take to reach the surface. Additionally, the higher pressures at greater depths allow for improved oxygen transfer. Typical aeration basin diffuser submergence depth is 14 to 17 feet. In most cases, SOTE is directly proportional to diffuser submergence depth. In full-floor diffuser systems, diffuser submergence depth is approximately one foot less than the basin liquid depth (side water depth).

Air flux is defined as the ratio of total diffuser air flow to the total active diffuser membrane area. For a submerged orifice or porous membrane, an increase in air flow results in a larger bubble size. Additionally, higher flux rates cause the air bubbles to coalesce, which further reduces the surface area at the air-water interface. Consequently, SOTE generally decreases as the flux rate is increased.

Diffuser density is defined as the active membrane area divided by the total aeration basin floor area. Higher diffuser density translates into an even distribution of active membrane area on the basin floor and minimizes air-induced velocity gradients. Higher diffuser density results in higher SOTE.

Note that an increase in the number of diffusers within a basin would increase diffuser density and reduce air flux, which results in a greater SOTE. In modern aeration system design, SOTE is a verifiable performance metric for aeration equipment.

When converting SOTE to OTE a number of system conditions and operating parameters must be considered, as shown in the equation below:

Where:

OTR = Oxygen transfer rate, lb/hr or lb/d,
SOTR = Standard oxygen transfer rate, lb/hr or lb/d,
$\alpha = k_{La}$(process water)/k_{La}(clean water), dimensionless
k_{La} = Mass transfer coefficient, 1/hr
Θ = Temperature correction factor = 1.024, dimensionless
T = Process water temperature, °C
β = 0.95 to 0.99, dimensionless
Ω = Pressure correction factor = P/P_s, dimensionless
P = Atmospheric pressure at site location, psia
P_s = Standard atmospheric pressure = 14.7 psia
$C^*_{\infty 20}$ = Equilibrium dissolved oxygen (DO) concentration at 20°C, 760 mm barometric pressure, and zero salinity = 9.07 mg/L
C = Basin DO concentration, mg/L

With the exception of alpha (α), the variables on the right side of this equation are well defined, or defined by system parameters. Alpha must be estimated based on a consideration of many influencing factors.

The results of the off-gas testing at the Tapia WRF indicate that the current OTE within the aeration basins ranges from 4 to 11 percent. Expected values of OTE for aeration basins of comparable depth are between 12 and 16 percent. The OTE values within the aeration basins at the Tapia WRF are approximately 50 percent lower than OTE values found at comparable facilities.

Aeration basin air flow data was collected for September 2010 and January 2011. This data is presented visually (by time of day) in Figure 4.3 for September 2010 and Figure 4.4 for January 2011. The data is arranged so that an entire month of data is plotted over a 24-hour period. During September 2010 the air flow meter serving aeration basin 5 was out of service.

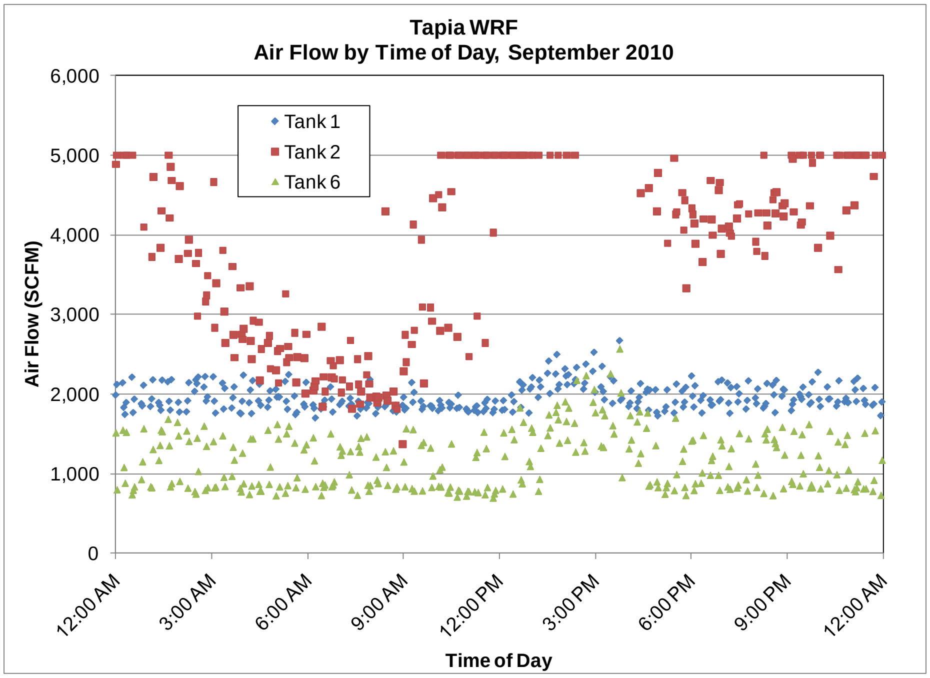


Figure 4.3 Aeration Basin Air Flows During September 2010

An inspection of Figures 4.3 and 4.4 reveals the following observations:

- *The monthly air flow data shows a strong correlation with time of day*. The upstream aeration basins (basins 2 and 5) show a minimum air flow occurring between 5:00 and 9:00 AM. Diurnal maximum flow occurs between 11:00 AM and 2:00 PM. Diurnal maximum flows in downstream aeration basins (basins 1 and 6) occur between 2:00 and 4:00 PM.
- *Aeration basin air flow measurements do not exceed 5,000 scfm.* This may be due to blower, air flow meter, or software limitations. This is most likely a software limitation. As such, it is possible that actual air flows may regularly exceed 5,000 scfm.
- *Air flows show large diurnal variations.* Air flows to the upstream aeration basins range from a diurnal minimum of 2,000 scfm to a diurnal maximum of 5,000 scfm (possibly higher). During January 2011, diurnal air flows within aeration basin 6 regularly increase from 700 scfm to 2,300 scfm.

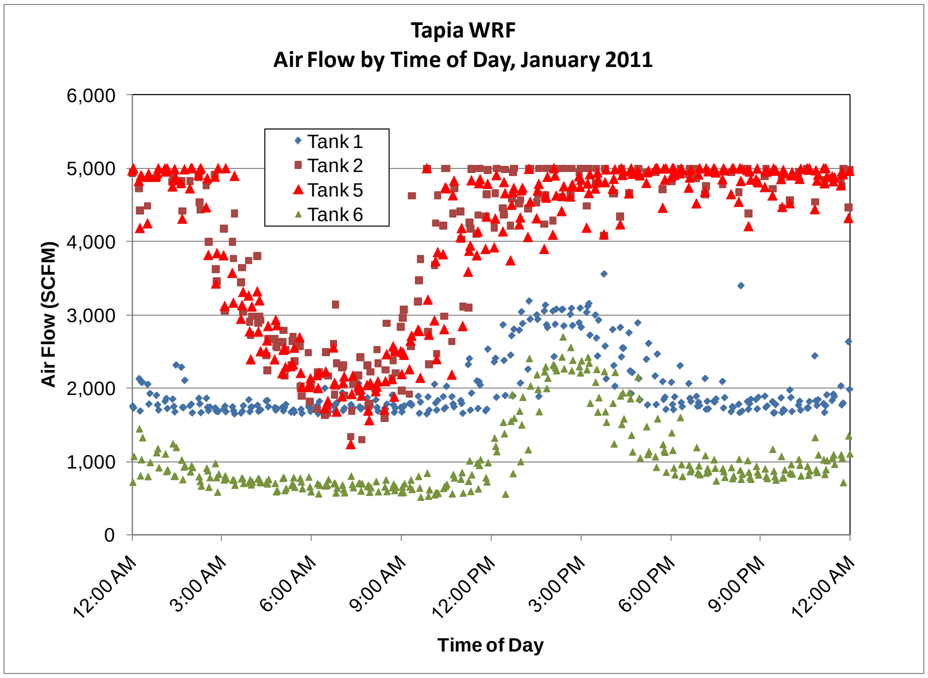


Figure 4.4 Aeration Basin Air Flows During January 2011

The observed variations in diurnal air flows are significant. Figure 4.5 presents a comparison of OTE data collected during off-gas testing with projected OTE values provided by a full-floor diffuser system. The existing system exhibits a sharp decline in OTE at high flux rates. It is important to note that the projected OTE values for a full-floor system shown in Figure 4.5 are estimated based on a theoretical model and the points form a smooth curve. This is in contrast to the empirical data collected from the existing system.

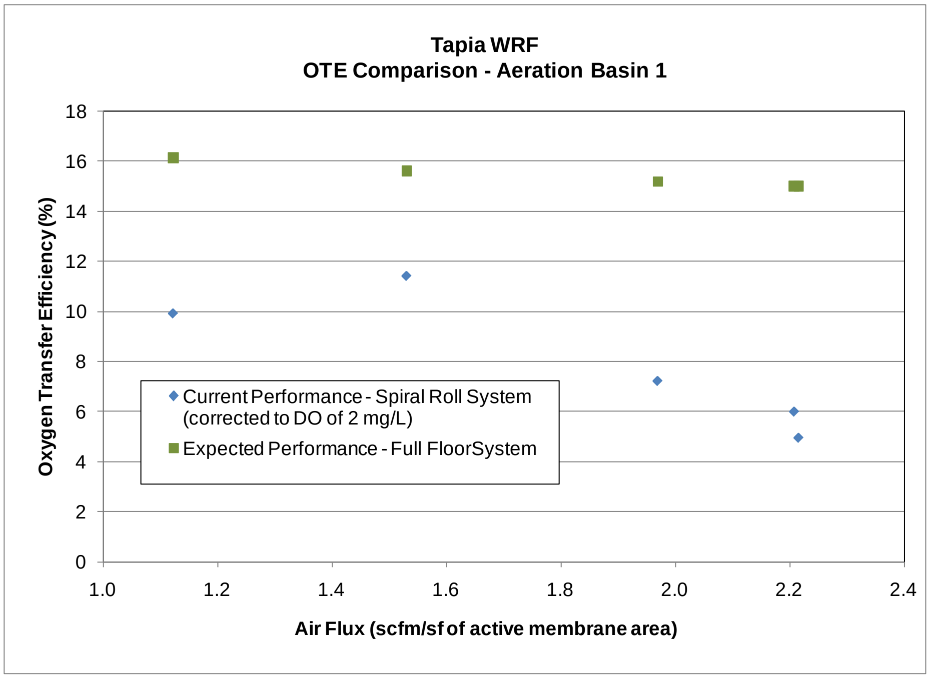
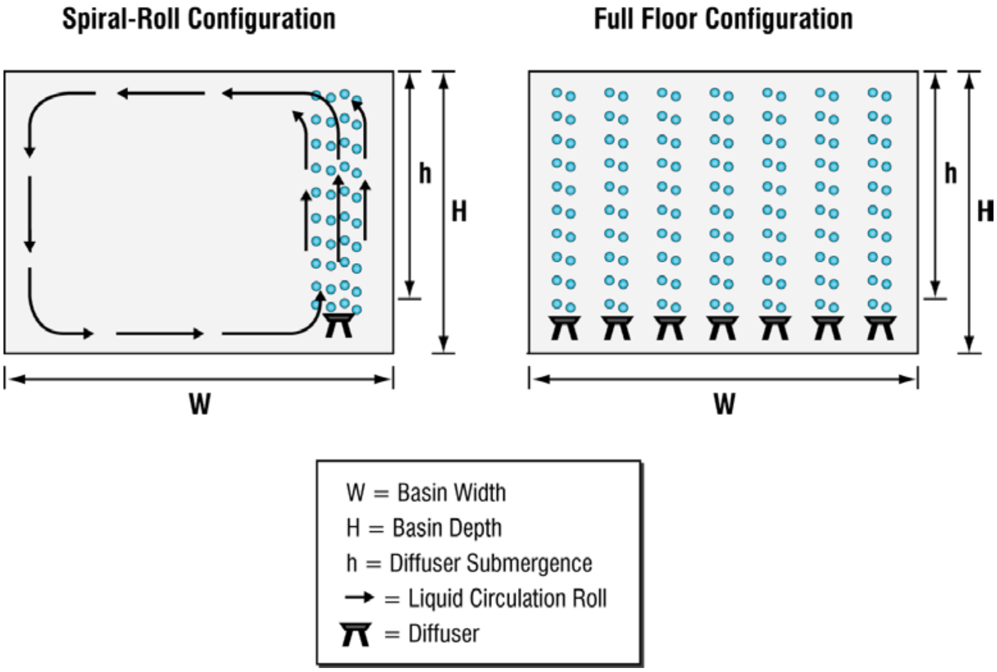


Figure 4.5 OTE Comparison – Existing Spiral-Roll vs. Full-Floor System

The sharp decline in OTE at high flux rates demonstrated by the existing diffuser system can be attributed to a spiral-roll flow pattern within the existing aeration basins. The spiral-roll pattern results from the current swing-arm diffuser configuration and is illustrated in Figure 4.6.



.

Figure 4.6 Comparison of Aeration Basin Diffuser Configurations

As air flows to the existing basins are increased, the velocity of the circular roll pattern shown in Figure 4.6 is also increased. The result is a reduced air bubble mean residence time, which subsequently reduces OTE. This circular roll pattern is not characteristic of a full-floor cover system, shown on the right of Figure 4.6.

The large diurnal variations in air flows to the aeration basins support the observation that OTE within the basins drops significantly at higher air flows. Consequently, the existing aeration system is least efficient during periods of high influent flows and/or during peak loading events.

The DO profiles included in Appendix A indicate a problem with current DO control within the aeration basins. The profiles show that DO concentrations in Aeration Basin 2 are well above the setpoint of approximately 2 mg/L. Maintaining elevated DO levels require higher air flows which correspond to a reduction of OTE within the aeration basins.

The location of the DO probe in Basin 2 - adjacent to swing Zone 2B – is likely the cause of the problems with DO control. A strong spiral roll pattern (both longitudinally and laterally) at this location results in a reduced local OTE and subsequent tendency toward low DO levels. Maintaining a DO of 2 mg/L at this location within the aeration basin results in elevated DO concentrations throughout the rest of the basin. High liquid velocities within the existing spiral-roll system limit how far the DO probe can be moved upstream. With a full-floor cover diffuser system, high liquid velocities would not occur, and the location of the DO probe may be optimized (typically located two-thirds of the distance along the aerobic zone).

4.1.2 System Analysis

Theoretical oxygen demands within the aeration basins at the Tapia WRF were calculated based on current average and future peak conditions. Primary effluent loads used to simulate the current average and future peak conditions are presented in Table 4.1.

Table 4.1 Aeration Basin Oxygen Demand Parameters
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Parameter	Current Average Condition	Future Peak Condition
Influent Flow, mgd	**9.3**	**12.0**
Primary Effluent Quality		
BOD, mg/L	124	184
TSS, mg/L	90	105 (85)
NH4-N, mg/L	27.5	37.5
TKN, mg/L	38.1	50.3
Water Temperature, °C	22.5	17
MLSS, mg/L	1,800	3,100
Aerobic Zones	First 33% of Re-aeration Basins First 78% of Aeration Basins 2 & 5 Last 78% of Aeration Basins 1 & 6	First 33% of Re-aeration Basins 100% of Aeration Basins 2 & 5 100% of Aeration Basins 1 & 6

The current average condition reflects average values of data collected from calendar years 2009 and 2010. Operating data representing the future peak condition was obtained from the recent AECOM biological nutrient removal upgrades project. Note that the primary effluent total suspended solids (TSS) concentration already exceeds the listed design value of 85 mg/L (AECOM). A primary effluent TSS concentration of 105 mg/L was substituted to account for reduced primary clarifier performance at higher flows and above-average design concentrations.

The future peak condition shows much higher Biological Oxygen Demand (BOD) and Total Kjeldahl Nitrogen (TKN) concentrations than the current average conditions reflect. As a result, the future peak primary effluent BOD and TKN concentrations are 91 and 70 percent higher than the current average, respectively.

Process modeling in Biotran^{TM} was performed to simulate the theoretical oxygen transfer rate (OTR) required to maintain a DO concentration of 2 mg/L in each aerobic zone. Oxygen demands (in terms of OTR) for the aeration basins representing current average conditions are presented in Table 4.2.

Table 4.2 Aeration Basin Oxygen Demands - *Current Average Condition*
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Location	**OTR (lb/day)**	**SOTR (lb/day)**	**Air Flow (scfm)**
RAS Re-aeration Basins	1,235	3,860	470
Aeration Basins 2 and 5	4,480	9,740	1,200
Aeration Basins 1 and 6	1,430	3,030	345
Total			
With RAS Re-aeration	14,290	33,260	4,030
Without RAS Re-aeration	*11,820*	*27,200*	*3,090*

The air flows presented in Table 4.2 are based on a full-floor cover diffuser configuration installed in the aeration and RAS re-aeration basins. The exact air flows will depend on the specific diffuser selected, and the diffuser count, as explained in section 4.1.1.

Oxygen demands (in terms of OTR) for the aeration basins representing future peak conditions are presented in Table 4.3. The air flows shown in Table 4.3 are based on a full-floor cover diffuser configuration installed in the aeration and RAS re-aeration basins.

Table 4.3 Aeration Basin Oxygen Demands - *Future Peak Condition*
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Location	**OTR (lb/day)**	**SOTR (lb/day)**	**Air Flow (scfm)**
RAS Re-aeration Basins	2,020	5,825	745
Aeration Basins 2 and 5	11,440	27,140	3,650
Aeration Basins 1 and 6	5,270	12,210	1,575
Total			
With RAS Re-aeration	37,460	90,350	11,940
Without RAS Re-aeration	*33,420*	*78,700*	*10,450*

The OTR values presented in Tables 4.2 and 4.3 are based on operating the downstream basins (aeration basins 2 and 1 on the west side and basins 5 and 6 on the east) fully aerobic (i.e., no secondary anoxic zone). To prevent loss of denitrification, and the corresponding increase in secondary effluent nitrate-nitrogen, the re-aeration basins would be operated at a low DO concentration of 0.1 mg/L. As a result of a relatively low alpha and high oxygen demand, this zone would always tend to have a low DO concentration. The future design for the re-aeration basin would include the option of operating it at a DO concentration of 2 mg/L. The higher DO concentration would be facilitated by installing a full floor cover diffuser system to the first two aeration zones, so that 67 percent of the RAS re-aeration basins may be operated aerobically. The third zone within the reaeration basins would remain unaerated to facilitate denitrification and reduce the DO concentration of the RAS prior to reintroduction into the aeration basins. The operator would have the choice to operate the second zone in either aerobic or anoxic mode.

4.1.3 Recommended Improvements

We recommend that the District replace the existing spiral-roll aeration system within the aeration basins with a full-floor cover system. A discussion of the proposed replacement diffuser system follows.

A conceptual layout of the proposed full-floor cover diffuser system is presented in Figure 4.7. Basic features of the proposed system include the following:

- The proposed full-floor system would maintain the existing dual-serpentine flow configuration within the aeration basins. The existing swing-arms and diffusers serving Aeration Basins 3 and 4 would remain. These basins would continue to function as anoxic zones.

- The existing air mains serving Basins 1, 2, 5, and 6 would be replaced with new stainless steel piping. The existing 42" steel process air header within Gallery No. 3 would remain.

- The new air mains serving Basins 1, 2, 5, and 6 would be equipped with thermal dispersion flow meters that would minimize head loss and associated operating costs.

- The current aeration control strategy would be maintained. A single DO probe would be located in each aeration basin. The location of the DO probe would be optimized to ensure a uniform DO profile within the aeration basin. A control valve would regulate air flows to each basin based on the DO setpoint and the air flows measured by the thermal dispersion flow meter. An evaluation of the costs and benefits of adding Most Open Valve (MOV) variable header pressure control will be performed as part of the blower evaluation.

- The air mains to each basin would serve three or four separate drop legs, each equipped with a manual butterfly value, to facilitate the manual balancing of air flows within aeration zones. Plant operators would retain the option to operate swing Zones 1B and 2B as un-aerated zones.

The proposed diffuser system layout presented in Figure 4.7 is based on the installation of tube diffusers, such as those supplied by Environmental Dynamics Incorporated (EDI). Similar configurations could be achieved using diffusers supplied by another manufacturer. The choice of diffuser can be postponed to ensure competitive bidding for the diffuser system replacement project.

Plug flow conditions are maximized by the current serpentine flow arrangement within the aeration basins. Plug flow provides the most efficient use of a given reactor volume. In wastewater treatment, plug flow conditions also help to minimize the growth of filamentous bacteria that can cause undesirable sludge settling characteristics. Undesirable sludge settling characteristics are typically associated with a sludge volume index (SVI) of 150 mL/g or higher.

A mixed liquor return pump was installed in each of the aeration basins as part of the recent nutrient removal upgrades. These pumps facilitate the operation of six basins in a parallel flow arrangement. Alternatively, two basins within a single serpentine configuration may be operated in parallel if a single basin is taken out of service.

Parallel operation of the basins in their current configuration would provide only limited denitrification. The spiral-roll pattern created by the existing diffusers prevents effective isolation between aerated and un-aerated zones within the basins. In order to achieve high levels of denitrification during parallel operation it would be necessary to install a baffle between the aerated and un-aerated zones of each basin. The baffle would improve denitrification during normal operation. From a review of current plant operating data, it appears that current denitrification is sufficient to meet effluent requirements during normal operation. As will be discussed, parallel operation of the aeration basins would be limited as a plant reliability measure when it becomes necessary to remove a basin from service, and would not be done during periods of discharge to receiving streams. As such, a high level of denitrification would not be required during parallel operation and the expense associated with the installation of baffles within each aeration basin does not seem justifiable.

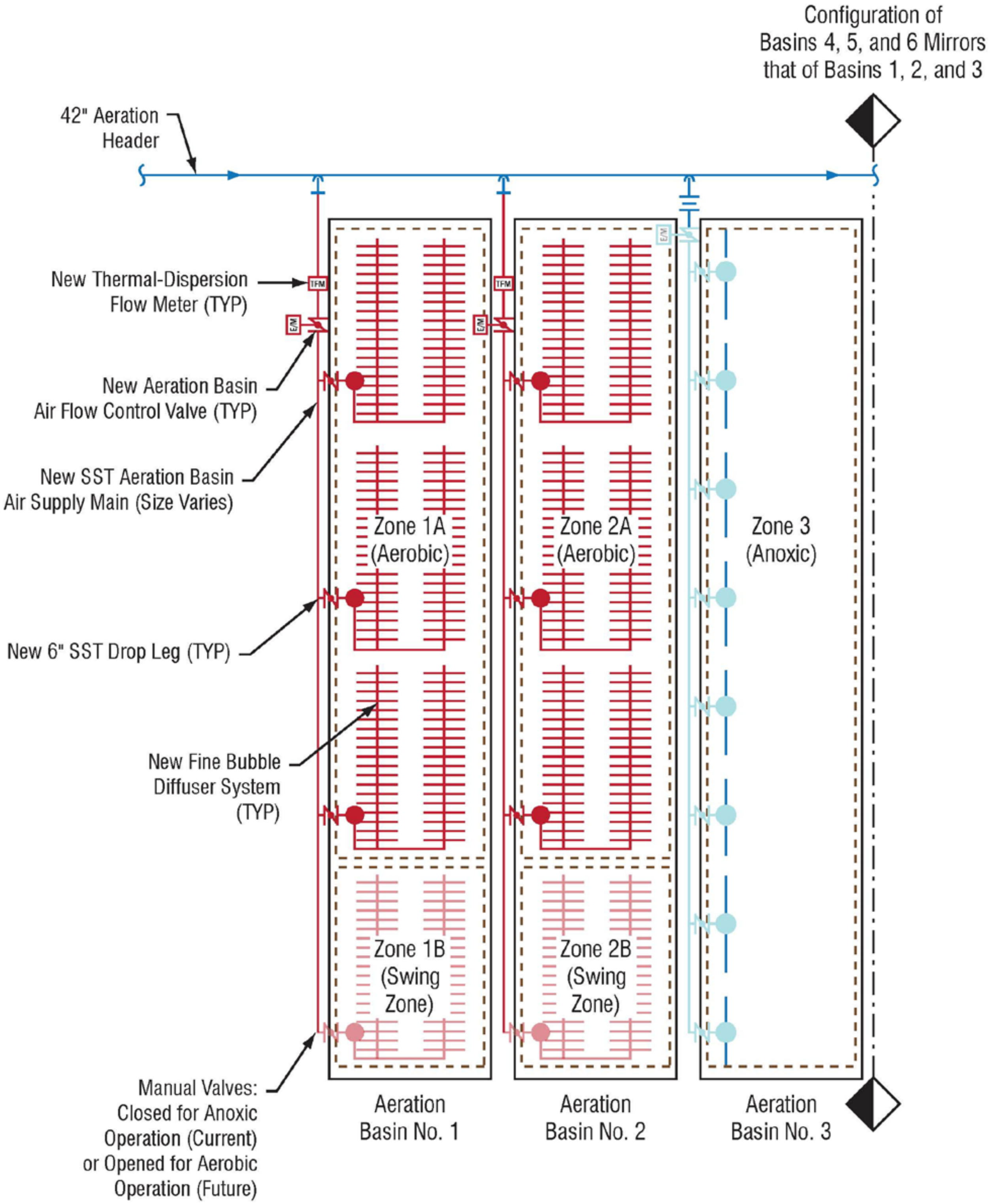


Figure 4.7 Proposed Full-Floor Diffuser System

In the future, should it become necessary to remove a basin from service, reliability requirements may be met by incorporating the following operational strategies:

- An aeration basin should be removed from service only during the summer months. During the summer, nitrification can be maintained at reduced SRT levels. Unlike a clarifier, where mechanical failure may necessitate the immediate removal of a unit from service, an aeration basin may be kept in operation for several months until the wastewater temperature increases.
- Three basins may operate in a serpentine flow configuration, with one basin operating in parallel. For example, Basins 4, 5, and 6 would continue to operate in serpentine mode if maintenance were required on Basin 2. Basin 1 would remain in parallel operation. This would be considered Reliability Mode No. 1 (Table 4.4).
- It would be possible (but not necessary) to operate normally un-aerated Basins 3 and 4 in parallel. The existing (to remain) spiral-roll diffuser configuration within these basins would result in increased air demands. The operator would still have the option of putting Basin 3 or 4 in service. This mode of operation would require higher air flows than Reliability Mode No. 1, due to the low OTE of the spiral roll system, which would not be changed in Basins 3 and 4, as these basins are fully anoxic during normal operation. This would be considered Reliability Mode No. 2 (Table 4.4).

Modeling in Biotran shows that, at wastewater temperatures above 20°C (68°F), the incorporation of the reliability strategies described above would be sufficient to ensure full nitrification. The flow split under these conditions would be 75 percent (9 mgd at the design flow of 12 mgd) to the serpentine system and 25 percent to the parallel basin.

The diffuser layout of the proposed full-floor cover diffuser system allows for parallel operation. The most demanding condition, from a perspective of diffuser system design, is the operation of Basins 1 or 6 in parallel, as these basins have the lowest diffuser density.

A summary of expected aeration basin air demands for the proposed full-floor cover system is presented in Table 4.4.

Table 4.4 Summary of Expected Aeration Basin Air Demands
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Condition	Aeration Basins Only	Including RAS Re-Aeration Basins(1)
Current Minimum	1,500	2,000
Current Average	3,100	4,030
Current Peak	6,250	8,470
Future Peak – Normal Operation	10,500	11,950
Future Peak – “Reliability” Mode 1(2)	11,175	13,540
Future Peak – “Reliability” Mode 2(3)	18,100	20,300

(1) Assumes a full-floor cover diffuser system in the RAS re-aeration basins.
(2) Two aeration basin out of service (worst case Basins 2 or 5 as well as 3 or 4).
(3) One aeration basin out of service (worst case Basins 2 or 5). High air flow is due to low efficiency of remaining spiral roll system in Basins 3 and 4.

As can be observed from Table 4.4, the highest aeration air demands occur when the previously discussed reliability strategies are implemented. During operation in “reliability” mode, some diffusers are taken out of service (worst case Basins 2 or 5 out of service) and SRT is reduced. Both of these factors reduce OTE.

Current average conditions, as presented in Table 4.4, include 930 SCFM of air flow to the RAS re-aeration basins. This air flow increases to 2,365 SCFM during future peak conditions when operating in “reliability” mode No. 1. As noted in Table 4.4, these air flows assume a full-floor cover diffuser system installed within the RAS re-aeration basins. The installation of a full-floor cover diffuser system within these basins may be postponed until limitations of the existing aeration equipment negatively affect effluent quality (ammonia breakthrough).

BioTran modeling indicates that ammonia breakthrough in the plant effluent would occur at an average plant influent flow of 11 MGD during peak loading and winter temperatures. Preliminary planning-level construction costs for the RAS re-aeration basin diffuser system improvements are approximately $474,000. This includes the installation of diffusers in two zones per basin. These improvements do not provide a substantial energy savings but facilitate the treatment of plant design flows (12 MGD).

The improvements to the aeration basin diffuser system may increase the blower discharge pressure requirements although it is not expected that the increase will be significant. The slight increase in required blower discharge pressures is a result of the greater diffuser submergence depths typically achieved with a full-floor cover system. The current blower discharge header pressure setpoint is approximately 7.5 psig. The projected blower discharge pressure required for a new full-floor cover system will vary between 7.74 psig (current average conditions) and 7.92 psig (future peak conditions). Expected blower discharge pressures were determined using Carollo’s standard tools for calculating pressure loss in air piping and diffuser system performance projections provided by the membrane system supplier (EDI). They include allowances for additional pressure losses due to dirty membranes and will vary based on the specific membrane type and supplier selected for the improvements project.

Preliminary planning-level construction costs, 20-year lifecycle costs, and carbon footprint reductions for the recommended aeration basin diffuser improvements are presented in Table 4.5. Lifecycle costs for each diffuser system configuration (existing and proposed) are relative to estimated current operation and maintenance costs.

Table 4.5 Aeration Basin Diffuser System Improvements - Lifecycle Cost Evaluation
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Parameter	Units	Diffuser System Configuration	
		Existing Spiral-Roll System	Proposed Full-Floor Cover System
Preliminary Planning-Level Construction Costs$^{(1)}$	($)	0	1,376,000
Annual Costs			
Energy$^{(2)}$	($/Yr)	345,104	229,838
Maintenance$^{(3)}$	($/Yr)	14,400	19,552
20-Year Lifecycle Present Worth Ownership Costs$^{(4)}$	($)	4,520,055	4,580,623
Annual Carbon Footprint$^{(5)}$	(Tons CO_2/Yr)	2,042	1,360

Notes:
(1) Includes costs for materials, installation, and startup.
(2) Energy costs based on $0.0845/kWh SCE energy rate.
(3) Maintenance costs based on replacement of 20 percent of diffusers per year. Diffuser replacement costs estimated to be $36 per diffuser for existing system and $47 per diffuser for new full-floor cover system.
(4) Lifecycle ownership costs based on a 6 percent discount rate.
(5) Carbon footprint based on a composite SCE energy emissions factor of 1.00 lbs CO2/kWh.

The full-floor cover diffuser system would provide an annual energy savings of approximately $115,000. This annual energy savings would provide an estimated simple payback period of 11.9 years. A detailed preliminary estimate of construction costs for a full-floor cover diffuser system is included for reference in Appendix B.

Energy efficiency rebates from SCE are expected to reduce the capital cost for this improvement by up to $138,000. This would reduce the lifecycle costs of the full-floor cover system to approximately $4,443,000. This represents a lifecycle costs savings of approximately $77,400 over the existing spiral-roll diffuser system.

4.2 Channel Mixing

Process air is currently used for mixing within the process channels at the Tapia WRF. The desired objective of mixing within the process channels is to maintain solids in suspension. Two types of channel aeration systems in common use today are spiral-roll and complete grid. The large majority of channel aeration systems in current use (including those at the Tapia WRF) are of the spiral-roll variety. Figure 4.8 presents both types of channel aeration systems.

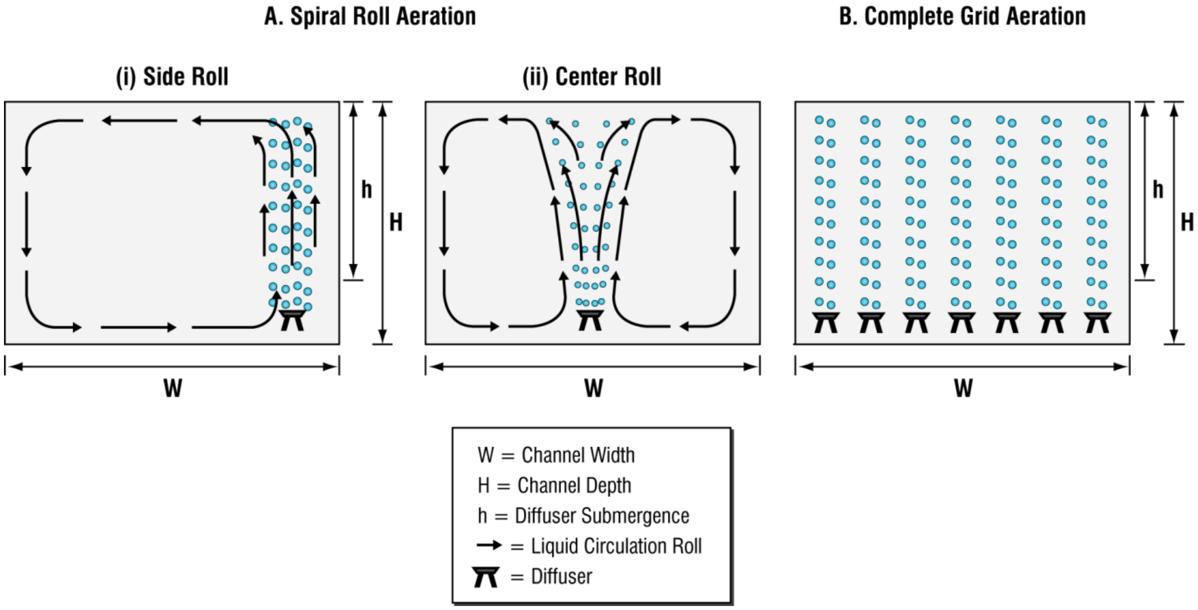


Figure 4.8 Channel Aeration Systems

As shown in Figure 4.8, aeration in spiral-roll systems is facilitated by a single row of diffusers running along the bottom of the channel. The single row of diffusers may be located along one wall of the channel (side roll configuration) or along the center (center roll). In either spiral-roll configuration, a liquid circulation pattern is created by the air lift action of the diffused air bubbles. Complete grid systems are not commonly used for channel mixing.

Research performed by Carollo's B. Narayanan (A Rational Approach to Channel Aeration Design, 1998) indicates that suspension of solids within a channel equipped with a spiral-roll aeration system can be achieved by maintaining a minimum liquid velocity at the channel bottom. A spiral-roll pattern significantly increases the channel bottom velocity. It is this channel bottom velocity that generates the forces necessary to prevent solids settlement. The minimum bottom velocity required to maintain a solid particle in suspension is a function of particle size and specific gravity. Narayanan, et al.[2] show that the minimum bottom velocity required to prevent settlement of mixed liquor particles is

---

[2] B. Narayanan, "*A Rational Approach to Channel Mixing*", Carollo Engineers, 1998

between 0.3 and 0.5 feet per second. This conclusion is corroborated by the WPCF Manual of Practice[3], which recommends a minimum bottom velocity of 0.5 fps in degritted wastewaters. Minimum bottom velocities in channels containing particles heavier or lighter than mixed liquor are adjusted using the methods described by Narayanan et al. Higher bottom velocities are required in channels containing heavy particles (degritted influent). Lower bottom velocities are sufficient to maintain light particles in suspension (return activated sludge). As previously discussed, the lift action of the rising air bubbles generates a spiral-roll pattern within the channel. An increase in air flows, with a corresponding increase in energy transferred to the liquid within the channel, will increase the spiral rotational velocity. The increased rotational velocity, in turn, translates into a higher bottom velocity. Narayanan et al. characterizes the air flows (per unit channel bottom area) required to maintain a desired bottom velocity within a channel of known dimensions.

4.2.1 Existing Channel Air System

During site visits to the Tapia WRF, the project team observed many over-aerated segments of channel and several segments that were not aerated at all (see Figure 4.9). Contributing to the imbalance of air supply within the channels is the condition of the aging channel aeration system. The project team observed many broken and capped drop legs, plugged diffusers, and broken valves. Several segments of the primary clarifier feed , mixed liquor, and common aeration basin feed channels were un-aerated due to the poor condition of the aeration system.

Figure 4.9 Un-aerated Segment of Mixed Liquor Channel

Bottom velocities within the channels were recorded using two Global Water^{TM} velocity probes, (models FP-101 and FP-210). Each probe has an accuracy of ±0.1 fps and a minimum range of about 0.3 fps. During testing, it was observed that bottom velocities were close to zero at most locations within the channels. Bottom velocities were locally high (up to 1.5 fps) near operating air diffusers but quickly fell to near zero at a distance of about 2 - 3 ft from air diffusers. This phenomenon indicates the lack of a developed spiral-roll pattern within the channels caused by air flow “dead-zones” resulting from the condition of the existing aeration piping, valves, and diffusers. Air flow was visibly high at locations where

---

[3] WPCF (Water Pollution Control Federation, now Water Environment Federation) (1985). Manual of Practice No. FD-8, *Clarifier Design*. WEF, 601 Wythe Street, Alexandria, VA, 22314-1994

drop legs were intact, diffusers were not plugged, and drop leg valves were operational. The project team adjusted the valves at these locations to facilitate mixing without creating a high level of turbulence at the water surface.

Grab samples (250 ml) were collected near the channel bottom and within six inches of the water surface before and approximately two hours after adjustments to air flows were made. Determinations of Total Suspended Solids (TSS) concentrations were made by the Tapia WRF laboratory. The TSS data provided by the laboratory was used as a surrogate for solids stratification before and after air flow adjustment. Adequate mixing was presumed to exist where the maximum deviation of TSS concentration was within 10% of the average value at a particular location. Results of the TSS testing are presented in Table 4.6.

The results of the air flow adjustments, as presented in Table 4.6, indicate that the reduction in air flows within the channels did not result in increased solids stratification (and subsequent settling) at the locations where the samples were taken. Care must be applied when interpreting the information presented in this table. Grab samples were typically collected near intact air valves and drop legs. The data presented in Table 4.6 indicates only that, prior to air valve adjustment, air flows were excessive at these locations. Many locally un-aerated sections of channel have a four to six- inch layer of sediment at the channel floor.

One important observation from Table 4.6 is that solids within the RAS channel showed little tendency to settle even after mixing air flows were turned completely off. This is readily apparent by the low variation (by percent deviation) of TSS with elevation in the RAS channel. There was no evidence of settling in any of the samples collected from the RAS channel three hours after collection.

One explanation for the apparent lack of solids settling within the RAS channel is that the RAS has completely settled within the secondary clarifiers and is not subject to further settling during the short residence time within the channel. Additionally, the turbulence caused by RAS spilling over the V-notch weirs into the RAS channel from the secondary clarifiers promotes mixing and helps to maintain solids in suspension.

The orifice plate air flow meters serving the process channel are not functional. Determinations of the exact air flow rate to each channel could not be made. Estimates of current channel air flows were made by comparing blower production flows before and after valves isolating each channel’s aeration piping were closed.

The design of the existing system for the transfer of mixed liquor provides very few points of free surface discharge. As a result, the system functions as a foam-trap. During heavy foaming events, the operators commonly increase channel air flows to break up surface foam within the mixed liquor channel. Future structural modifications to the aeration basins and mixed liquor channel should include provisions for foam removal by free discharge to the secondary clarifiers.

Table 4.6 Channel TSS Distribution
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

			Max % TSS Deviation	
Channel	**Channel Location**	**Adjustment Description**	**Before Adjustment**	**After Adjustment**
Grit Chamber Effluent	North End	Reduced air flow.	5%	1%
	Middle	Reduced air flow.	6%	4%
	South End	Reduced air flow.	3%	8%
Primary Clarifier Feed(1)	East End	Reduced air flow.	43%	28%
	Middle	Reduced air flow.	4%	2%
	West End	Reduced air flow.	0%	6%
Common Aeration Basin Feed(1)	West End (head)(2,3)	N/A – no air flows.	5%	2%
	Middle(2,4)	Reduced air flow.	1%	1%
	East (termination)(2)	Reduced air flow.	3%	3%
Aeration Basin No. 3 Feed(5)	South End (head)	Reduced air flow.	1%	1%
	Middle	Reduced air flow.	1%	1%
	North (termination)	Reduced air flow.	1%	1%
Aeration Basin No. 4 Feed(5)	South End (head)	Reduced air flow.	1%	2%
	Middle	Reduced air flow.	0%	1%
	North (termination)	Reduced air flow.	0%	2%
Mixed Liquor(1,6)	West End (head)	Reduced air flow.	9%	8%
	Middle	Reduced air flow.	1%	N/A
	East (termination)	Reduced air flow.	1%	1%
	North of Basin 6(7)	N/A - No air flows.	0%	N/A
Return Activated Sludge (RAS)(1)	East End (head)	Stopped air flows.	1%	1%
	Middle	Stopped air flows.	1%	4%
	West (termination)	Stopped air flows.	1%	0%
		Average	4%	3.9%

Notes:

(1) Several broken drop-legs, broken valves, and badly corroded air piping.
(2) Several inches of settled solids deposited on channel floor.
(3) High levels of turbulence created by local RAS flows into channel. No air flows observed - drop legs capped or valves broken.
(4) No air flows in channel near (anoxic) Aeration Basins No. 3 and 4. First aerated segment of channel downstream of Basin No. 4.
(5) High initial air flow rates observed. All drop legs and valves intact and operational. Piping not as badly corroded as in the common aeration feed channel.
(6) High velocities observed where aeration basins flow into channel.
(7) No intact drop legs in channel segment north of Aeration Basin No. 6. Extensive foaming observed three (3) hours after air flow reductions.

4.2.2 Recommended Improvements

The aging channel mixing system at the Tapia WRF has reached the end of its useful life. Broken drop legs and valves have resulted in many un-aerated segments of channel. During visits to the facility, the project team observed a four to six-inch layer of channel floor sediment at un-aerated segments of the primary sedimentation and aeration basin feed channels. While TSS analyses of grab samples collected from within the channels suggest adequate mixing near intact drop legs and functional air valves, solids are settling to the channel floor at un-aerated locations. In addition, the asymmetrical spacing of intact drop legs and functional valves creates a condition of non-uniform air delivery. This non-uniform air delivery results in a weak spiral-roll pattern that is inadequate for mixing. The overall effect is an inefficient use of air within the process channels.

We recommend that the District replace the mixing systems within the Grit Chamber Effluent, Primary Clarifier Feed, Mixed Liquor, and Aeration Basin Feed channels. A discussion of three replacement alternatives follows.

4.2.2.1 Conventional Spiral-Roll Channel Mixing System

This alternative would replace the existing air diffusers, valves, and piping within the process channels. A general system schematic is presented in Figure 4.10.

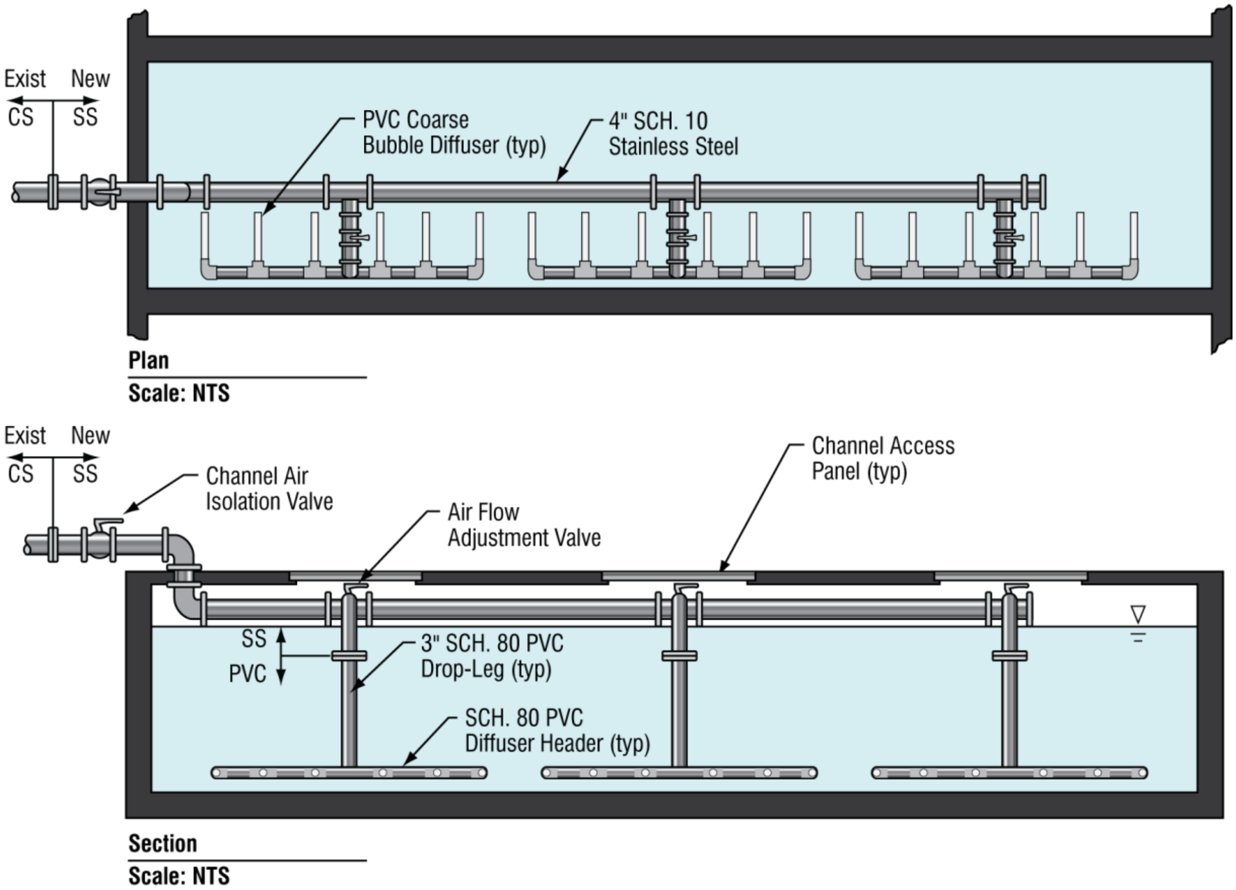


Figure 4.10 Conventional Spiral-Roll Channel Mixing System

The corroded carbon steel air mains within the channels would be replaced by stainless steel mains providing superior resistance to the corrosive gases present above the channel water surface. Stainless steel drop legs would be equipped with air flow adjustment valves at accessible locations. Submerged PVC diffuser headers would deliver air to self-purging, clog-resistant, coarse bubble diffusers. Engineering data sheets for coarse bubble diffusers typically incorporated by this system are provided for reference in Appendix C.

Estimated total mixing air demands for a conventional coarse-bubble spiral-roll channel mixing system are presented in Table 4.7. Preliminary planning-level construction costs and annual energy costs associated with this system are also presented in Table 4.7.

The air demands presented in Table 4.7 are based on experimental data and may be optimized after system installation. To facilitate the monitoring and control of air flows to each channel, we recommend that the existing orifice plate air flow meters and associated differential pressure elements serving each channel be calibrated, refurbished, or replaced as necessary. A detailed preliminary estimate of construction costs for this system is provided for reference in Appendix D.

Table 4.7 Conventional Spiral-Roll Channel Mixing Air Demands
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Channel	Particle S.G.	Minimum Bottom Velocity (ft/s)	Minimum(1) Air Flow (SCFM)
Grit Chamber Effluent	1.02	0.75	400
Primary Clarifier Feed	1.02	0.75	1,000
Common Aeration Basin Feed	1.01	0.53	500
Aeration Basin No. 3 Feed	1.01	0.53	400
Aeration Basin No. 4 Feed	1.01	0.53	400
Total Channel Mixing Air Demand (SCFM)			2,700

Notes:
(1) Minimum air demands based on research performed by B. Narayanan et al. (1998).

4.2.2.2 High-Pressure /Large-Bubble Channel Mixing System

This alternative would replace the existing air diffusers, valves, and piping within the process channels with a proprietary channel mixing system designed, manufactured, and installed by EnviroMix LLC. This system facilitates channel mixing by firing short bursts of compressed air through engineered nozzles fastened to the floor of each channel. Compressed air is intermittently fired in fractional second durations. The large, softball-sized bubbles created by the nozzles minimize surface area at the air-water interface within the channel. The large bubbles rise to the channel surface faster than the smaller bubbles generated by a conventional coarse bubble system. These factors combine to minimize the transfer of oxygen to the wastewater, providing efficient anoxic mixing. Minimizing oxygen transfer is especially desirable in the common aeration basin feed channel upstream of the anoxic zones within aeration basins 3 and 4.

A preliminary estimate of construction costs for this system is included for reference in Appendix D. A general system schematic is provided in Figure 4.11.

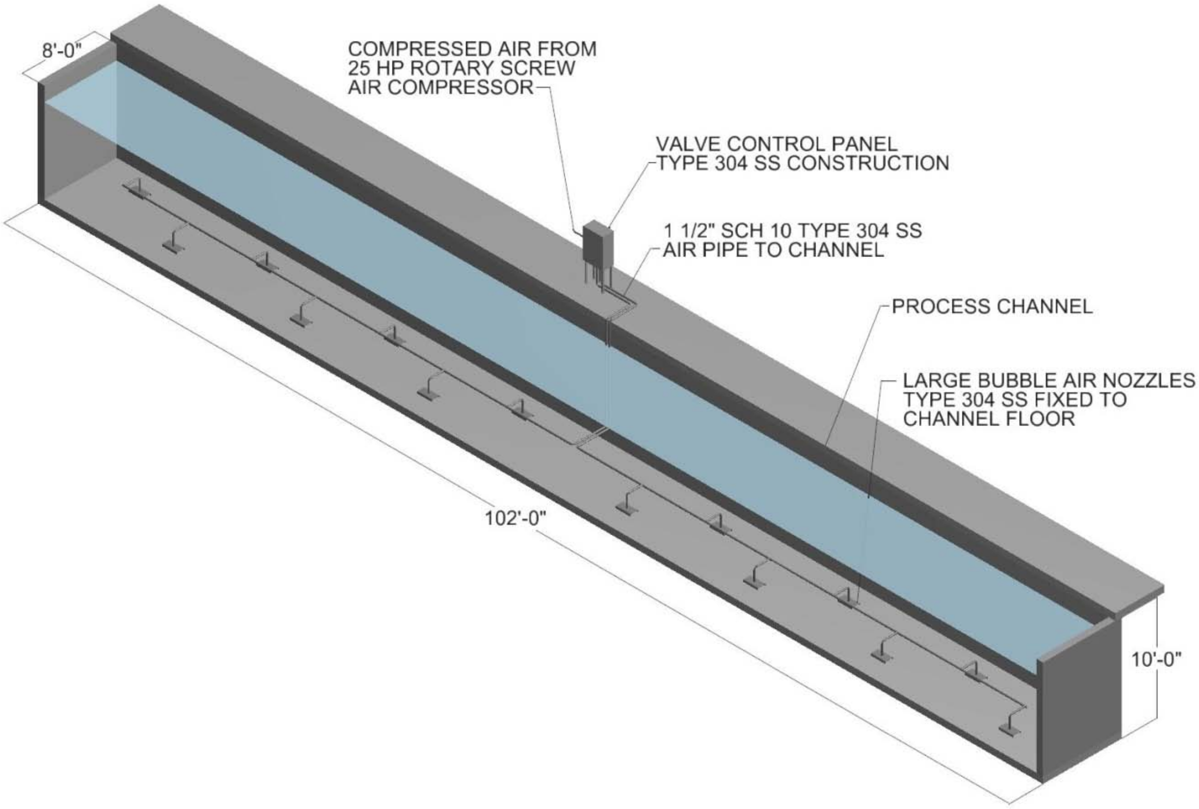


Figure 4.11 High-Pressure/Large-Bubble Channel Mixing System

A valve control panel (VCP), equipped with a programmable logic controller (PLC), and mounted above the center of each channel, would control the firing of solenoid valves to deliver short bursts of compressed air through engineered nozzles fixed to the channel floor. A single centrally located, variable speed, rotary screw air compressor would supply air at approximately 100 psig to each VCP.

One of the benefits provided by a high-pressure/large-bubble mixing system is the reduced energy costs when compared with the conventional aerated channel mixing alternative. A single 25 hp rotary screw air compressor would supply the total air required for channel mixing at the Tapia WRF.

4.2.2.3 Pumped-Mix Channel Mixing System

A pumped-mix channel mixing system incorporates centrifugal pumps that deliver water at high velocities through elastomeric variable orifice nozzles installed at the bottom of each channel at one side along its length. The primary function of a pumped-mix system is to maintain liquid velocities along the entire length of the channel floor greater than the minimum channel bottom velocities required to maintain solids in suspension. Typical velocities through mixing nozzles range between 10 and 20 feet per second. Preliminary design criteria for a pumped-mix channel mixing system at the Tapia WRF are presented in Table 4.8.

Table 4.8 Pumped-Mix Channel Mixing System Preliminary Design Criteria
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Channel	Wetted Volume (gal)	Pumping Flow Rate (gpm)	Required Pumping Power (hp)
Grit Basin Effluent	9,275	400	0.85
Primary Clarifier Feed	42,412	1,100	6.40
Common Aeration Basin Feed	60,319	1,400	10.35
Mixed Liquor	59,659	1,400	11.50
		Total Required Pumping Power	29.10

A nozzle spacing of approximately 3 feet would be incorporated along the channel wall. The pumping action would create a spiral-roll pattern in the channel similar to that created by a conventional channel aeration system. A single submersible pump would be installed within each channel. Alternatively, horizontal centrifugal pumps may be installed on equipment pads near each channel. The limited space available near the process channels at the Tapia WRF may preclude the use of horizontal centrifugal pumps.

A fixed header constructed of high density polyethylene (HDPE DR17) would deliver water from the discharge of the submersible pump to the nozzles submerged within the channel. The header would be located above the gravity drain water surface elevation within each channel to facilitate inspection and maintenance of the submerged header and mixing nozzles.

A preliminary estimate of construction costs for this system is included for reference in Appendix D.

4.2.3 Financial Evaluation of Channel Mixing Alternatives

Preliminary planning-level construction costs, annual operation and maintenance costs, 20-year lifecycle costs, and total carbon footprint for each replacement channel mixing system are summarized in Table 4.9. In this table, lifecycle costs for each alternative are relative to estimated current operation and maintenance costs.

Table 4.9 Channel Mixing Alternatives - Lifecycle Cost Evaluation
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

		Alternative[1]		
Parameter	**Units**	**Spiral-Roll**	**Large Bubble**	**Pumped Mixing**
Preliminary Planning-Level Construction Costs[2]	($)	400,000	732,000	428,000
Annual Costs				
Energy	($/Yr)	70,000	11,800	16,100
Maintenance	($/Yr)	0	3,500	935
20-Year Lifecycle Present Worth Costs[3]	($)	1,200,000	907,400	623,000
Annual Carbon Footprint[4]	(Tons CO_2/Yr)	412	70	96

Notes:
(1) Alternatives assume no mixing is required in the RAS channel.
(2) Includes costs for materials, installation, and startup.
(3) Lifecycle ownership costs based on a 6% discount rate.
(4) Carbon footprint based on a composite SCE energy emissions factor of 1.00 lbs CO2/kWh.

It is worth noting that the annual energy costs associated with the large bubble (EnviroMix) and pumped mixing systems are significantly lower than those associated with the conventional spiral-roll alternative. Energy costs for the large bubble mixing system are based on the continuous operation of a 25 hp rotary vane air compressor supplying compressed air to each valve control panel (VCP). Energy costs for the pumped mixing system are based on a total pumping power requirement of 29.1 hp. Energy costs for the conventional spiral-roll mixing system are based on the continuous operation of the process air system blowers at an estimated wire-to-air efficiency of 65 percent.

While the conventional mixing system requires a lower capital investment, both the pumped mixing and large bubble systems provide a significant 20-year lifecycle cost savings due to reduced energy requirements

4.3 Aerated Grit Chamber

The Tapia WRF is equipped with two aerated grit removal chambers at the plant headworks downstream of the mechanical bar screens. Separation of grit from lighter organic particles is facilitated by a spiral-roll liquid circulation pattern induced by the introduction of air through coarse bubble diffusers located near the floor along one side of each chamber. Typical design air flows for aerated grit chambers range between 3 to 8 SCFM per linear foot of chamber length.[4]

4.3.1 Current Air Use

Design air flows for the aerated grit chambers at the Tapia WRF are 150 SCFM per chamber (Headworks Rehabilitation Drawing G-3). This is equivalent to an air delivery rate of 4.2 SCFM per linear foot of chamber length (existing chambers are 36 feet long). This is within the range of design air flow rates required to maximize grit removal while minimizing the removal of organic material. Plant operations do not currently monitor air flow rates to the grit chambers.

During the mid-morning hours (between 6:00 and 9:00 AM) demand for process air at the plant is at a minimum. During this interval the lead Roots blower shuts down and two Hoffman blowers fulfill process air demands. A 36-inch check valve is installed in the process air piping between the Roots and Hoffman blower stations. This check valve does not consistently seat (close) when reversal of flow occurs. During a site visit, the externally weighted lever of the check valve was manually forced back and held in place during flow reversal. This caused the check valve to seat properly. During the early morning hours when the lead Roots blower is offline (Hoffman blowers operating), and the check valve seats, air to the aerated grit chambers is shut off. The lack of an air supply during the morning hours effectively eliminates any spiral roll pattern within the chamber. The subsequent increase in organics removal can result in a highly putrescible grit that acts as an odor nuisance and insect attractant once removed from the chamber.

4.3.2 Recommended Improvements

The optimum air flow rate within an aerated grit chamber can vary depending on plant influent flows and grit characteristics. For this reason, it is important that a method of monitoring air flows to each chamber be provided and utilized. The air flows within each grit chamber at the Tapia WRF are supplied by three swing-arm riser assemblies. Each riser assembly is equipped with an upstream air flow control valve. The orifice plate air flow meters installed within the six-inch risers serving each grit chamber measure pressure drop only and provide no direct indication of air flows. We recommend replacing the analog differential pressure gages serving these flow meters with gages calibrated to display air flow (in SCFM) so that air flows to the grit chambers may be monitored and controlled.

We also recommend the removal of the 36-inch check valve installed between the Roots and Hoffman blower stations. The removal of this check valve will not adversely affect the operation of the existing blowers (each Roots blower is equipped with a discharge check valve) and will ensure that process air reaches the grit chambers during the early morning hours when only the Hoffman blowers are operating.

---

[4] Metcalf and Eddy, *Wastewater Engineering* (New York: McGraw Hill, 2003, 4th Ed.), pg. 389.

4.4 Conveyance System Leakage

The air conveyance system at the Tapia WRF consists of the following basic components:

- Process air piping and fittings
- Air flow meters
- Valves (isolation, control, check, etc.)

4.4.1 Evaluation of Conveyance System Leakage

Much of the air conveyance system at the Tapia WRF is aging and corroded. Air leakage at several locations is plainly audible and the exact location of leakage can be readily determined without the need for special equipment. At other locations, the source of leakage is more difficult to isolate and more sophisticated detection methods are required.

A field survey was performed to determine the extent of air leakage from the process air conveyance system. Ultrasound technology (UE Systems UP-9000) was utilized to pinpoint small air leaks, leaks at areas with high levels of background noise, and leaks at areas of the plant difficult to access. The UP-9000 measures the ultrasonic frequencies generated when air expands rapidly through a leak in the conveyance system.

The sound pressure (dB) recorded by the instrument was correlated with an estimate of leakage rate (SCFM) based on the working pressure within the system. In total, thirty-seven leaks were discovered in the aboveground air piping. The physical location of each leak was recorded and tagged with a blue wax pipe marker.

A graph of leakage rates (SCFM) vs. sound pressure (dB) is provided in Figure 4.12

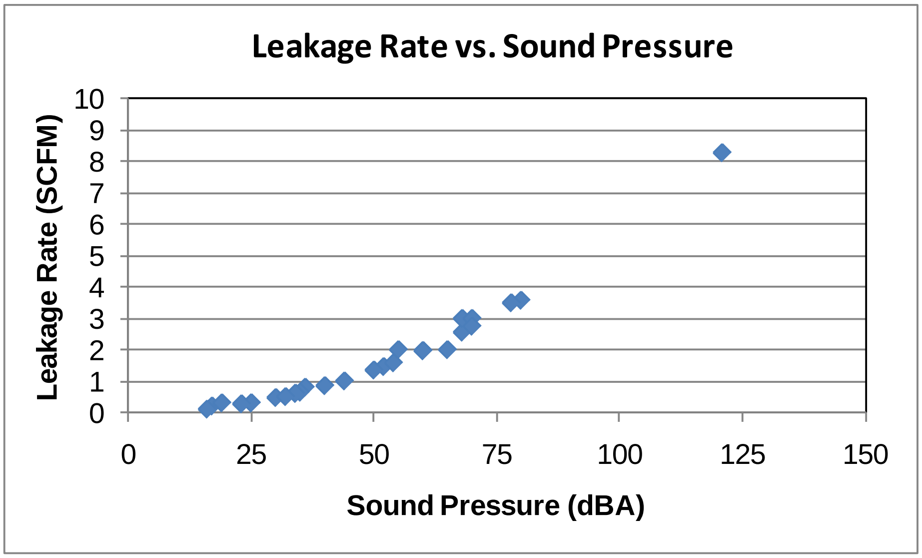


Figure 4.12 Leakage Rate vs. Sound Pressure

A squared relationship between the recorded sound pressure and leakage rate can be observed from Figure 4.12.

Detailed leak descriptions, annual energy costs, estimated repair costs, and simple payback periods for leaks having a “worst-case” payback period of less than ten years are summarized in Appendix E. The annual energy cost savings provided by repairs to the leaks presented in Appendix E is approximately $14,000. The total estimated costs to repair these leaks are between $2,000 and $6,000. The simple payback period is between 0.15 and 0.43 years.

The annual energy costs associated with each leak were calculated based on the estimated leakage rate, current energy rates, and estimated wire-to-air efficiencies of the existing blowers.

The leak survey did not detect leaks originating from buried air piping. Due to relatively low pressures (about 7.5 psig) within the conveyance system and the average depth (2 - 4 ft) of the buried piping, underground leaks were undetectable by ultrasonic equipment. Based on discussions with plant operators, leaks in the buried piping exist and are manifest by bubbles rising to the ground surface through grass and asphalt paving during heavy rain events. Leaks in buried air piping at wastewater treatment plants are not uncommon. Cooling of the air within buried piping (occurring at ground temperatures) causes water vapor to condense and puddle in low areas within the system. This condensate is corrosive and can cause leakage if provisions for drainage are not included during original pipe installation. At locations where underground leakage is known to exist, and the piping is accessible for excavation, we recommend excavating buried flanged connections and expansion joints to inspect for leakage.

Much of the buried piping at the facility, such as the buried 42-inch diameter air piping between the CCP-B canopy and the RAS re-aeration basins, is difficult to access for excavation. We recommend that the magnitude of the leaks discovered during an excavation of the more accessible buried piping be used as a value benchmark before a decision is made to excavate and repair buried piping in less accessible locations. A schematic of the process air piping system at the Tapia WRF is provided in Appendix F.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The engineering analysis in this technical memorandum indicates several opportunities to reduce process air demands and conveyance system pressure losses at the Tapia WRF:

- The existing spiral-roll diffuser configuration within the aeration basins demonstrates sub-standard oxygen transfer efficiency (OTE). It is expected that a replacement of the existing spiral-roll diffuser system with a full-floor cover system together with the relocation of the existing basin DO probes would result in an expected 69 percent reduction of annual average air usage within the aeration basins.
- The existing channel aeration system has reached the end of its useful life and does not represent an efficient use of process air for mixing within the channels. The replacement of the existing channel aeration system with a new conventional spiral-

roll system will increase the air usage within the channels by approximately 29 percent but the resulting improvement in mixing within the channels will represent a more efficient use of process air. Process air demands within the channels may be eliminated through the incorporation of a large-bubble (proprietary) or pumped-mix channel mixing system.

- The replacement of the analog differential pressure gauges at the air mains serving the aerated grit chambers with analog gages calibrated to display air flow (SCFM) will facilitate the monitoring and control of air flows to the aerated grit chambers. The removal of the existing 36-inch check valve between the Hoffman and Roots blower stations will ensure a reliable supply of air to the aerated grit chambers during the early morning hours.
- The repair of leaks from the aboveground air piping at the Tapia WRF would reduce process air usage by an estimated flow of 500 SCFM. Repairs to most of the leaks discovered represent a simple payback period of less than one year and would save the District an estimated $14,000 in annual energy costs.

Table 5.1 presents the reduced air demands facilitated by the improvements recommended within this memorandum. Most significant is the 70 percent reduction in current average aeration basin air demand provided by the proposed diffuser system upgrade.

Table 5.1 Reduced Current Process Air Demands
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

	Reduced Current Air Demands (SCFM)		
Location	**Minimum**	**Annual Average**	**Peak**
Grit Chambers	150	150	300
Channel Mixing(1)	2,700	2,700	2,700
Aeration Basins	1,500	3,090	6,250
RAS Re-aeration Basins	500	940	2,220
Filter Backwash Scour(2)	0	0	300
Leakage(3)	500	500	500
Total	5,350	7,380	12,270

Notes:

(1) Channel mixing flows based on the installation of a new spiral roll mixing system.
(2) Intermittent usage. Each of twelve plant effluent filters backwashed an average of once per day. Air scour period lasts approximately 5 minutes per filter backwash cycle.
(3) Estimated underground leakage.

Table 5.1 indicates that current average process air demands may be reduced to 7,380 SCFM through an incorporation of the improvements recommended within this memorandum. The flows presented in Table 5.1 represent a 49 percent overall reduction in annual average process air demands. This reduction in overall process air demand translates into smaller blowers, lower operating costs, and reduced carbon footprint.

Blower design criteria based on reduced air demands are presented in Table 5.2. The system pressure presented in Table 5.2 is based on recommendations by the diffuser system manufacturer and the assumption that the existing orifice plate flow meters at the discharge of the Hoffman blowers will be replaced with thermal dispersion meters (reduced pressure requirements).

Table 5.2 Design Criteria for Blower Alternatives
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Parameter	Unit	Value
System Pressure(1)	(psig)	7.75 to 7.92
Current Minimum Air Demand	(SCFM)	5,350
Current Average Air Demand	(SCFM)	7,380
Current Peak Air Demand	(SCFM)	12,270
Future Peak - Normal Operation	(SCFM)	15,750
Future Peak - “Reliability” Mode 1(2)	(SCFM)	17,340
Future Peak - “Reliability” Mode 2(3)	(SCFM)	24,100

Notes:
(1) Assumes a full-floor cover diffuser system in the RAS re-aeration basins.
(2) Two aeration basins out of service (worst case Basins 2 or 5 as well as 3 or 4).
(3) One aeration basin out of service (worst case Basins 2 or 5). High air flow is due to low efficiency of remaining spiral roll system in Basins 3 and 4.

The next phase of the process air evaluation will evaluate blower replacement alternatives to satisfy blower turndown requirements and minimize lifecycle costs of ownership.

The expected average annual plant flows will be less than what can be met by the turndown of the existing Roots blowers – i.e., the Roots blowers are oversized for the reduced plant flows. As part of the blower evaluation, our team will investigate the benefits of replacing the Roots and/or Hoffman blowers with newer, more efficient blowers – sized for expected future air flows.

A financial summary of the improvements discussed within this memorandum is presented in Table 5.3. In this table, lifecycle ownership cost savings for each improvement are relative to estimated current operation and maintenance costs.

For the preliminary construction costs a sales tax of 9.8 percent and a contingency of 20 percent have been added as well as 12 percent for contractor overhead and profit. The cost estimates also include 15 percent for engineering, legal, and administration fees as well as a 5 percent owner’s reserve for change orders.

Table 5.3 Financial Summary of Improvements
Tapia WRF - Process Air Evaluation
Las Virgenes Municipal Water District

Improvement	Annual Energy Savings ($/Yr)	Preliminary Planning-Level Construction Costs ($)	20-Year Lifecycle Cost Savings[1] ($)
Aeration Basin Diffusers	115,000	1,376,000[2]	77,400[3]
Re-aeration Basin Diffusers	5,700	474,000	(441,000)
Channel Mixing[4]	(15,500)	400,000	(577,600)
Leak Repairs	13,800	6,000	168,000
Total	119,000	2,256,000	(773,200)

Notes:

(1) Lifecycle cost savings are compared against existing equipment and are based on a 6% discount rate. Lifecycle costs savings are shown as present worth.
(2) Energy efficiency rebates from SCE are expected to reduce the capital costs associated with the replacement of the aeration basin diffusers by up to $138,000.
(3) Assumes a maximum SCE energy efficiency rebate amount of $138,000 toward the replacement of the aeration basin diffusers.
(4) Based on installation of a new conventional spiral-roll channel mixing system.

With the exception of channel mixing, all of the improvements provide an annual energy savings. The aeration basin diffuser improvements show a simple payback period of 11.9 years. The RAS re-aeration basin improvements do not result in a significant energy savings by themselves, but will be required to facilitate the treatment of design plant influent flows (12 mgd). It is expected that this improvement may be deferred until the plant influent flows reach approximately 11 MGD. This is expected to occur around project year 15 (calendar year 2027).

Energy efficiency rebates from SCE (Southern California Edison) are expected to reduce the capital cost associated with the replacement of the diffuser system in the aeration basins by up to $138,000. The reduced capital costs would result in a lifecycle costs savings of approximately $77,400 over the existing spiral-roll diffuser system.

The channel mixing improvement (assuming a new conventional spiral-roll system) does not provide an annual energy savings but does represent a more efficient use of process air due to improved mixing within the channels. If the large-bubble or pumped-mix channel mixing systems were installed, a net annual energy savings would be achieved with a corresponding 20-year lifecycle cost savings.

Appendix A

OFF-GAS TESTING REPORT

OFF-GAS TEST REPORT FOR THE TAPIA WATER RECLAMATION PLANT PERFORMED ON APRIL 22 AND JUNE 6, 2011

Michael K. Stenstrom
PO. Box 24894
Los Angeles, CA 90024

May 16, 2011 (draft)
June 7 2011

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

1. SUMMARY AND CONCLUSIONS

Off-gas testing was performed at the TAPIA Water Reclamation Plant on April 22 and June 6 2011. The tests were conducted to determine the performance of fine pore tube diffusers mounted on a classical "swing arm" design to produce a spiral roll fine pore aeration system. The tube diffusers are EDI FlexAir^{TM} T Series diffusers which are composed of EDPM rubber and are 91 mm (~3.6 in) diameter by 502 mm (~ 20 in) length. This is the first off-gas test performed at this plant. The diffusers were installed in 2005 as a direct replacement of coarse bubble spargers on swing arms. The goal of this test was to measure the current aeration efficiency in order to predict energy savings if the aeration system is upgraded.

The aeration tanks are arranged as two parallel systems of three tanks in a series "serpentine" plug flow arrangement. The first tanks are completely anoxic and a second anoxic zone exists at the end of Tank 2 and beginning of Tank 3.

The air flow rate in the tanks is extremely high, at least in the first aerobic tank and air flux peaks at approximately 1.48 scfm/ft^2 of tank area. This flow rate is more typical of a coarse bubble system that a fine pore system (0.4 to 0.6 scfm/ft^2). Due to the high air flow rate, it was not possible to test Tank 2 (first aerobic tank) with the existing hoods. The water surface is so turbulent that the hoods do not seal and allow air and off-gas to mix. Tank 3 operated at reduced air flow rate and was tested except for the anoxic zone position next to the anoxic zone (mixer hold down cables and circulating currents interfered with hood positioning). To obtain an estimate of the transfer efficiency in Tank 2, a second test was performed on June 6 using a 5 gallon bucket as a hood.

Table 1 shows the test results from April 22. The oxygen transfer efficiency (OTE, %) shows the actual, measured transfer efficiency at the existing temperature and dissolved oxygen (DO) concentration during the testing. The αSOTE shows the transfer efficiency, adjusted for temperature, barometric pressure, DO, and salinity; adjustments for the α factor are not made. The α factor is the ratio of the process water transfer efficiency to the clean water efficiency, and ranges between 0 and 1.0. The value of the α factor depends on the type of aeration device (e.g., fine bubble, coarse, surface, etc) and the properties of the liquid being aerated. Work by the author has confirmed earlier observations that α factors are strongly related to the SRT, with higher α factors being associated with higher SRTs. The α factor is also a function of diffuser condition. When diffusers age they may scale (inorganic materials), foul (organic materials) or may change properties due to chemical interactions.

Table 1. Transfer Results for Tank 1 (3rd Tank in the Serpentine Flow System)

Position	**Tank Distance**	**OTE**	**αSOTE**	**α**	**DO**	**Air Flux**		**O2 Uptake**
	(ft)	(%)	(%)		(mg/L)	(scfm/ft^2)	(scfm/diff)	(mg/L-hr)
4	70	7.2	9.1	0.52	2.0	0.45	2.56	34.4
5	90	6.6	7.5	0.45	1.2	0.51	2.87	35.3
6	110	4.8	6.1	0.36	2.2	0.51	2.88	25.4
7	130	11.1	14.2	0.78	2.2	0.35	1.99	40.9
8	150	9.9	12.5	0.64	2.0	0.22	1.46	22.8
	Avg	**7.9**	**9.9**	**0.55**	**1.9**	**0.41**	**2.35**	**31.7**

Notes: Air flux based on off-gas hood flow measurements. Plant instrumentation indicated ~ 1800 scfm during the testing for this tank, or 0.54 scfm/ft^2 of tank area and 3.64 scfm/ft^2 of active diffuser surface area. Diffuser active surface area = 1.3 ft^2/tube.

Table 2 shows the transfer efficiencies measured with the bucket hood. The air fluxes, a factor and O2 Uptake rates are not shown, since the hood is too small to obtain accurate estimates of air flow rate.

Table 2 Transfer Results for Tanks 1 and 2 using the Bucket Hood

Tank	**Position**	**Tank Distance** (ft)	**OTE** (%)	**αSOTE** (%)	**DO** (mg/L)
Tank 2	3	50	5.1	6.4	2.0
Tank 2	4	70	4.0	6.3	3.6
Tank 2	5	90	5.0	8.7	4.2
Tank 2	6	110	3.7	6.4	4.1
Tank 2	7	130	3.6	5.8	3.7
Tank 2	8	150	4.6	6.6	3.0
Average			**4.3**	**6.7**	**3.4**
Tank 1	3	50	4.6	5.5	1.7
Tank 1	4	70	5.5	6.9	2.1
Tank 1	5	90	5.2	7.0	2.5
Tank 1	6	110	5.1	6.9	2.6
Tank 1	7	130	5.1	6.6	2.2
Tank 1	8	150	6.3	7.9	2.0
Average			**5.3**	**6.8**	**2.2**

The transfer rates using the bucket hood correspond to the lowest transfer rates of the diffuser system, since the bucket captures off-gas just above the diffuser. The air bubbles following this path have the shortest retention time and therefore the lowest transfer rate.

For Tank 1, the average air flow as a function of active diffuser surface area is 2.35 scfm/ft^2 and corresponds to 17.8% SOTE at 12.4 ft of submergence, using EDI diffuser specifications. The transfer efficiencies are low compared to normal fine pore installations, and at 12.4 ft submergence, one would expect closer 14 to 16% αSOTE transfer rate. The α factor of 0.41 is a little less than typical of higher SRT activated sludge processes, but the measurements in this case are less reliable. Air flow rate was varying during the test (see Figures 8A and 8B). The first part of the aeration tank was not measured, and the first zones of plug flow aeration tanks usually have the lowest α factors; however, the high air flow rates in these zones produce conditions that are not typical of fine pore operation, and assuming low α factors may not be appropriate.

2. INTRODUCTION

2.1 Background

The Las Virgenes Municipal Water District (LVMWD) is a special water district that was established in 1958. The service area includes 122-square miles in western Los Angeles County and includes the incorporated cities of Hidden Hills, Calabasas, Agoura Hills and Westlake Village, as well as unincorporated areas. The District provides potable water, recycled water and wastewater service to a population of approximately 65,000. The Triunfo Sanitation District (TSD), located within Ventura County, is a joint powers authority (JPA) with LVMWD in wastewater and recycled water service. The TSD service area is 50-square miles with a population of 30,000. The JPA operates the Tapia Water Reclamation Facility (Tapia WRF) and The Rancho Las Virgenes Composting Facility. The Tapia WRF was originally constructed in 1965 to treat 0.5 million gallons per day (MGD). Several expansions have increased the plant to its current capacity of 12.3 MGD, treating wastewater to the tertiary level. Tapia WRF currently treats approximately 9.0 MGD which is disposed of through three different methods: recycled water use, the Los Angeles River or Malibu Creek. In 2003 and 2009, biological nutrient reduction modifications were constructed at the Tapia WRF. As a part of these modifications, anoxic zones were created in the aeration basins which resulted in a lower process air demand.

The plant was originally equipped with coarse bubble diffusers in a swing arm configuration with swings on one side of the tank. Such configurations are called "Spiral Roll" and are well known as the least efficient geometry for oxygen transfer (King, 1956; Morgan and Bewtra, 1960). Morgan and Bewtra found 6% clean water transfer efficiency (SOTE) at low to medium air flow rates at 11.5 feet of sparger submergence (spargers are a type of coarse bubble diffuser). Spiral roll aeration systems have been retrofitted with fine pore diffusers with significant improvements in efficiency, but they are still far less efficient than full floor coverage diffuser systems. For example, the EDI literature suggests that their spiral roll system with their fine pore tube diffusers can transfer approximately 15% SOTE at the a specific depth, while a full floor coverage system with the same type of diffuser can transfer more than 30% SOTE. A full floor coverage fine pore aeration retro fit at Tapia WRF would typically provide 2 to 2.5%SOTE/ft or 24 to 33 % for the most likely depth of a retrofit. One problem with using fine pore diffusers in a spiral roll configuration is having space to mount a sufficient number of diffusers to create a reasonable air flow per diffuser. The tight spacing creates high liquid velocities that rapidly “sweep” the bubbles out of the water.

Figure 1 shows the TAPIA treatment plant as it appears from Goggle Earth. The six parallel aeration tanks are shown in the middle right-hand side of the page. The red arrows, added by the author, show the flow of mixed liquor. The two center tanks are the influent tanks and flow progresses outward to the opposite sides of the structure. The tanks are numbered from left to right and Tanks 1 and 6 are the effluent tanks. The feed tanks are in the center, Tanks 3 and 4, and are not aerated. The differences in tank surface can be seen in the picture. The blue arrows show mixed-liquor recycle from the aerobic zone to the anoxic zone. Activated sludge processes with anoxic zones and recycle are often called “Modified Ludzack-Ettinger” or MLE. The process has a second anoxic zone which makes the process resemble a “Four Stage Bardenpho,” but the second anoxic zone is not isolated by baffles and has too high DO concentrations (at least during the testing) to be an effective denitrification zone.

Figure 2 is a diagram that shows the upper three aeration tanks which were tested. The figure shows the flow paths, anoxic mixers and details of the swing arms. The mixers are AquaDDM direct drive mixer-blenders, model 5900531, each at 5 hp.

The plant has three 250-hp multistage Hoffman centrifugal blowers rated at 4,400 scfm and 21.7 PSIA discharge pressure and 61.4% efficiency. The plant also has three 900 hp Roots single stage blowers, with synchronous motors, rated at 21,000 scfm, 21.6 PSIA discharge pressure and ~75% efficiency, equipped with inlet guide vanes for flow control. All use three phase 4160 VAC motors.

This report contains four appendices. Appendix A is a technical description of the off-gas procedure. Appendix B contains photographs of the plant, mostly taken during the testing. Appendix C shows the raw data and calculations. Appendix D contains additional plant information, including a drawing of the swing arms, dating back to 1987.

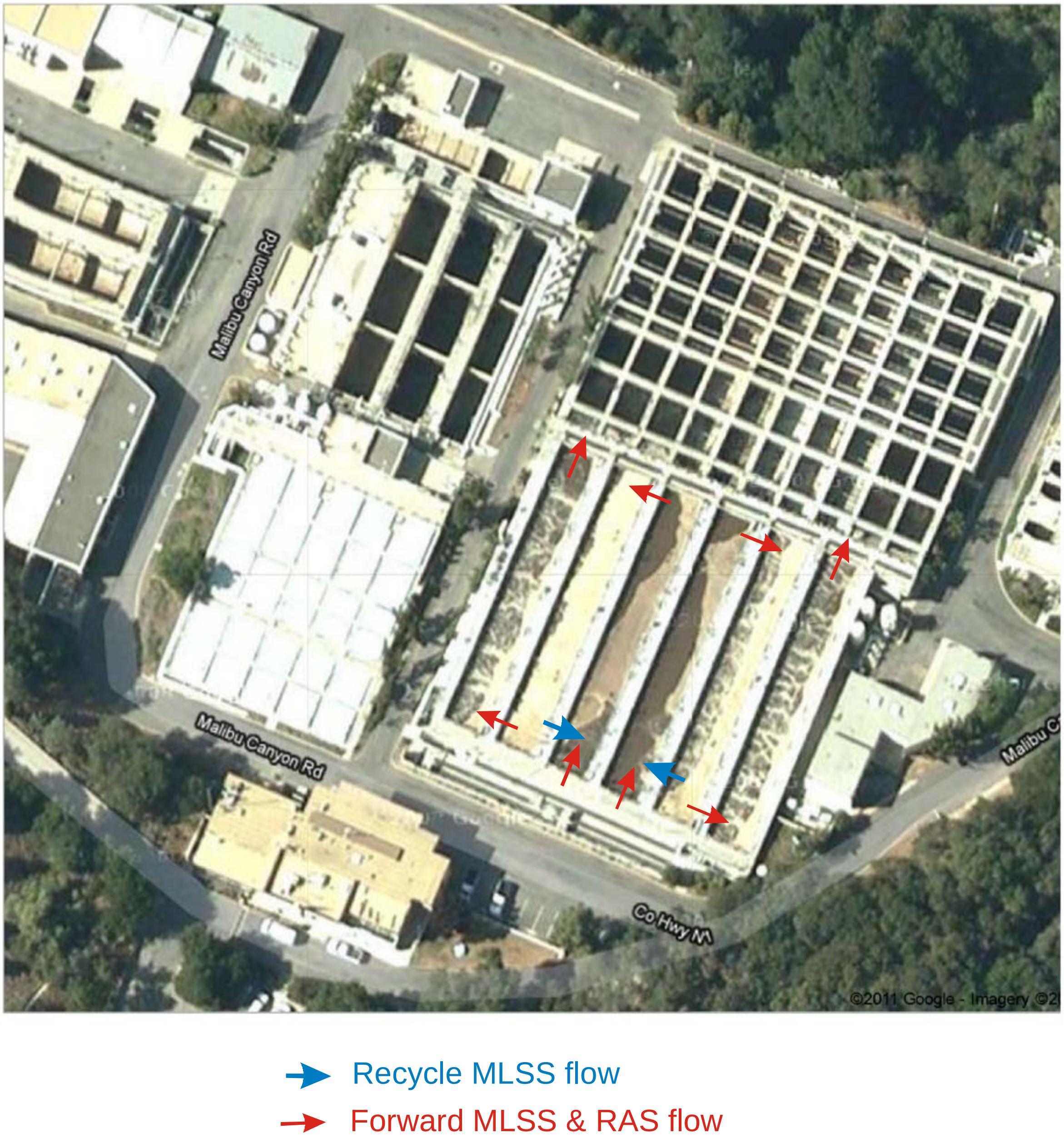


Figure 1. View of the Plant from Goggle Earth. Red arrows show mixed-liquor, RAS and influent flow. Blue lines show mixed-liquor recycle flow.

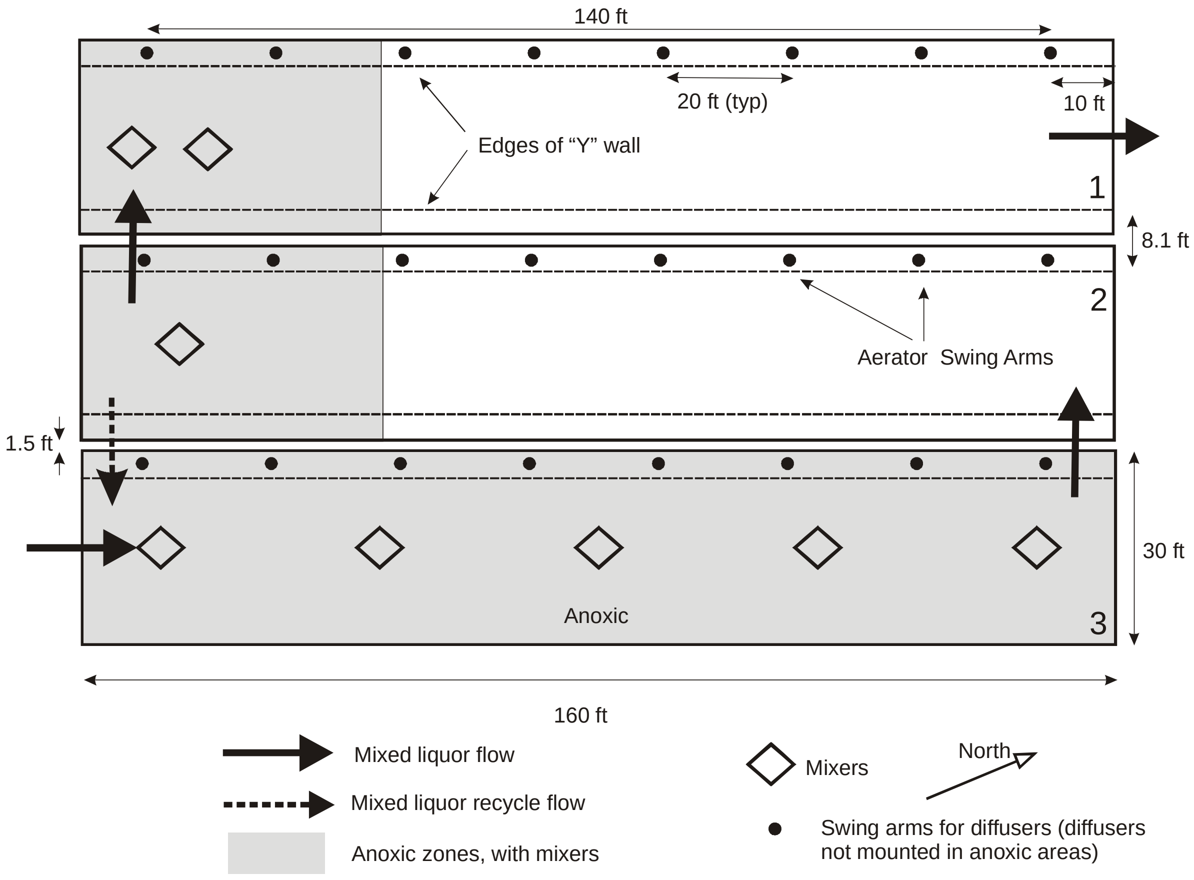


Figure 2. Schematic of three tanks, showing dimensions and major features. Each tank is equipped with eight swing arms, spaced 20 ft apart, and 10 ft from the ends of each tank. Anoxic zones are shown in gray, and zones are approximate for Tanks 2 and 3. The structural wall between tanks is 1.5 ft thick, and the top of "Y" wall is 8.1 ft wide. Side water dept varies due to sloping bottom but is approximately 14.1 ft and diffuser submergence is 12.4 ft. Diffusers are not operated on swing arms in anoxic zones, and some arms have been removed to accommodate recycle pumps. Swing arms have 72 bosses for diffusers with approximately 65 diffusers per arm. Some positions are not used due to the need for handrail clearance. The swing arm closest to the effluent in Tank 1 (also Tank 6, not shown) contains only 55 diffusers to restrict turbulence in the effluent channel.

2.2 Nomenclature and Terms

The following definitions and special terms are used in this report: Their use is consistent with the ASCE Standard (ASCE, 2006) and Standard Guide Lines (ASCE, 1997).

- DO = dissolved oxygen concentration, in mg/L.
- OTE = Oxygen transfer efficiency in percent. This is the percentage of the oxygen mass transferred from the gas phase to the liquid phase from the rising air bubbles. It is dependent upon the process conditions, such as dissolved oxygen (DO) concentration, temperature, barometric pressure, salt concentration, etc. This transfer efficiency is what is actually measured in an off-gas test.
- SOTE = Standard oxygen transfer efficiency in percent. This is the percentage of the oxygen mass transferred from the gas phase to the liquid phase from the rising air bubbles at standard conditions for dissolved oxygen (DO) concentration, temperature, barometric pressure, salt concentration, clean water, etc. One never obtains the SOTE in actual process operation. SOTE is determined by a clean water test, as described by ASCE (2006).
- OTR = Oxygen transfer rate in lb oxygen per hour. This is rate of transfer of oxygen mass from the gas phase to the liquid phase. It is dependent upon the process conditions, such as dissolved oxygen (DO) concentration, temperature, barometric pressure, salt concentration, etc. This transfer rate can be calculated from the OTE and the air flow rate, which is normally measured in an off-gas test.
- SOTR = Standard oxygen transfer rate in lb oxygen per hour. This is the rate of transfer of oxygen mass from the gas phase to the liquid phase at standard conditions for dissolved oxygen (DO) concentration, temperature, barometric pressure, salt concentration, clean water, etc. One never obtains the SOTR in actual process operation. SOTR is determined by a clean water test, as described by ASCE(2006).
- K_La = Volumetric mass transfer coefficient in units of hours^{-1}. This is a mathematical parameter calculated from transfer data to describe the rate of gas transfer. The SOTE can be calculated from the value of K_La and vice-versa.

- C_∞^* = Equilibrium DO concentration. This is the DO concentration that is achieved in clean water after being aerated for a very long time in order for the system to reach equilibrium (no changes in conditions over time). It is always greater ally than the saturation concentration listed in handbooks, which results because of the increased hydrostatic pressure of the water column on the rising bubbles.
- α factor = The α factor is the ratio of the value of K_La measured in process water to the K_La measured in clean water. The smaller the value of the α factor the greater the reduction in transfer rate due to contaminants in the process water (mixed-liquor). For diffusers that have been in service and are either fouled, scaled or compromised due to chemical interactions, an “F” factor is often used and the combination is reported as the αF factor.
- αSOTE = Oxygen transfer efficiency (OTE) corrected for all process conditions such as DO, salinity, barometric pressure, etc., except for the α factor. This is the single most useful parameter to describe the performance of an aeration system under process conditions. The αSOTE divided by the SOTE is equal to the α factor, or αF for fouled diffusers.

2.3 Scope

The purpose of this test was to provide information on the existing fine pore, spiral roll aeration system with the overall objective of predicting energy savings if the system were upgraded to more efficiency geometries.

2.4 Existing Conditions

The plant was operating at normal conditions on both days of testing. At about 10:30 AM the small, multistage blower was turned off and the large Roots single stage blower was turned on, and this blower operated until the test conclusion. Air flow rate was much higher with the larger blower, and the difference was easily observed from the turbulence at the tank surface. Table 3 shows the process parameters during the test and the day before.

Table 3. Process Conditions during the Tests

	4/21/2011	4/22/2011
Plant total effluent flow (MGD)	8.15	8.61
Return Activated Sludge Flow (MGD)		
Waste Activated Sludge Flow (MGD)		
MLSS	1910	1852
MLVSS/MLSS Ratio (%)	88	
Return Activated Sludge (TSS)	5128	5314
Primary Clarifier Effluent BOD_5	100	
Primary Clarifier Effluent TSS	67	
Primary Clarifier Effluent COD	240	
BOD_5 effluent	< 2	
NH_3-N influent	20.8	24.6
NH_3-N effluent	< 0.2	< 0.2
NO_3-N effluent	5.8	
Plant Influent pH	7.5	
Secondary Effluent pH	7.1	7.3
Alkalinity (as $CaCO_3$)		
SRT (days)	15	15
SVI (ml/g)	314	307
F/M (mg BOD_5/mg MLVSS-day)	0.058	0.060
Aeration Tank Temperature (ºC)		20.7

Concentrations all in mg/L unless otherwise noted. In some cases data are not collected daily (COD, BOD, Inf. pH, VSS/TSS ratio) and the last measurement before 4/22 is reported in the table. MLSS and SVI are averaged for Tanks 1, 2 and 3. F/M calculated using the data shown and aeration tank dimensions of 160 ft long by 30 ft wide by 14.1 ft SWD.

2.5 Testing Team

Professor Michael K. Stenstrom, from the Civil and Environmental Engineering Department at UCLA, acting as a private consultant, was retained by the Carollo Engineers to conduct the test. He was assisted by Dr. Ben Leu, also of UCLA and Coenraad Pretorius of Carollo Engineers.

3. TEST PROCEDURES

3.1 Off-Gas Tests

Off-gas testing was performed in the same fashion as described in previous reports and activities by the author (Stenstrom, 1990a and 1990b) and is consistent with the procedures described by the US EPA (1983) and ASCE (1997). It is based upon the original off-gas method (Redmon, et al, 1983). An extensive discussion of the test procedures and the mathematical basis are provided in Appendix A; therefore, only a brief explanation is included in the text of the report.

Off-gas testing is accomplished by capturing a quantity of gas being released from the surface of the aerated mixed-liquor. This gas is then passed through an analyzer that measures oxygen partial pressure (equivalent to oxygen mole fraction). The carbon dioxide and water vapor in the off-gas can either be measured or removed from the gas by drying. In the tests performed at TAPIA, the carbon dioxide and water vapor were removed from the off-gas prior to analysis using a desiccator filled with silica gel and flake sodium hydroxide.

The oxygen transfer efficiency (OTE) can be calculated from the off-gas oxygen mole fraction and the known ambient air mole fraction (20.95%). The off-gas flow rate is not needed to perform this calculation, although it is desirable for performing flow-weighted averages over an aeration tank or across several aeration tanks. The details of the calculation procedure and references for further reading are described in Appendix A.

Off-gas is collected in a floating hood. The hood was constructed of Fiberglas-coated and reinforced Styrofoam. The hood has capture dimensions of 10 feet long by 28 inches wide each, providing an area of 23.33 ft^2. The hood has a sharp under side edges to precisely define the capture area. The top ends of the hood are tapered, which permits the leading edge of the hood to be placed flush against the tank wall, even if the wall is angled. This type of hood geometry is required to accurately test tanks with "Y" walls.

Figure 3 shows the aeration tank and hood positions. To combine transfer efficiencies measured at different locations, flow-weight averages are used. To determine the efficiency versus tank distance, a flow-weighted average of at least two hoods across the width of the tank is used. An estimate for an entire tank or multiple tanks must also be calculated as a flow weight averaged.

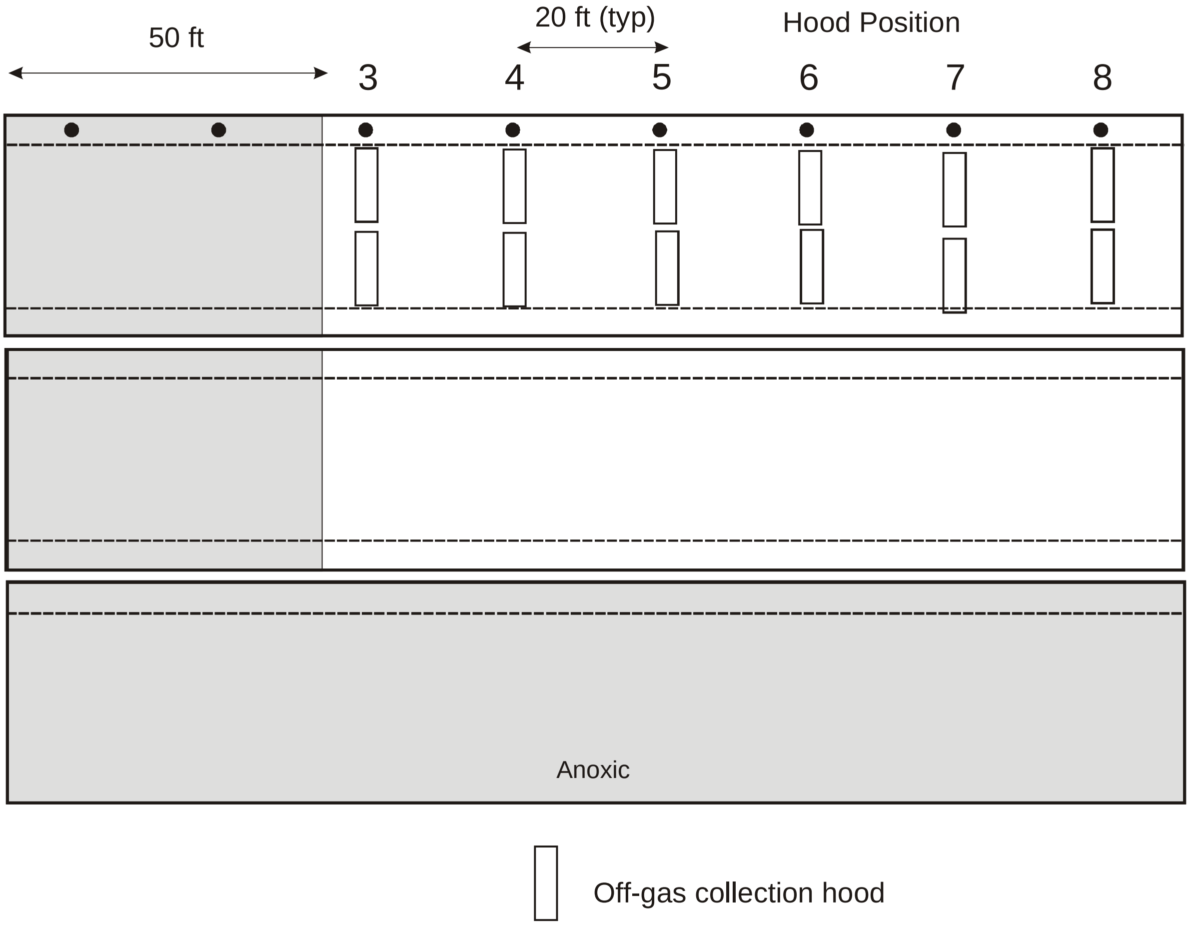


Figure 3. Off-gas hood positions. The upper position was directly above the diffusers and had high air flow rate. The lower position often had no measureable air flow rate. Only during peak air flow was air detectable at the lower hood position. There were strong velocity currents across the top of the tank surface at all air flow rates, but no off-gas at all but the highest air flow rates (see Table 1 for air fluxes).

Due to the inability to test Tank 2, a second test was performed using a 5-gallon bucket having an internal diameter of 10.25 inches which provided 0.57 ft^2 of capture area. The bucket hood was held in place using a 1.5 inch diameter PVC pipe and the end of the pipe was connected to the off-gas analyzer, in the same way as the large hood is connected. Even with this small capture area, it was difficult to manually hold the bucket hood in position. Off-gas captured in this way will have the lowest transfer rate since it is directly above the diffusers and the combined velocity of bubble rise and fluid upwelling creates a short bubble contact time. The tank average OTE and αSOTE will be higher than the average measured with the bucket hood. The average bucket hood OTE and αSOTE represent the greatest lower bound on transfer rates.

During the testing, the valves on the swing arms were all fully open, with the exception of the arms located closest to the anoxic zones (position 3 in Figure 3) in tanks 1 and 2,which were only half open.

3.2 Plant Operation

At the time of the testing no unusual conditions existed. Table 3 shows the key operating parameters for the plant. Most of the information in Table 3 does not enter into the aeration efficiency calculations, but is very helpful to understand the results. Oxygen transfer efficiency is dramatically affected by plant conditions. Generally the transfer efficiency is reduced at high F/M or low SRT. The plant operating conditions should be noted when comparing performance to other test results or other plants. *Nocardia*-like foam covered the tank surface except directly above the diffusers, but did not interfere with testing. It was much less than observed on April 13, when it covered the tanks in a thick layer in all areas except those directly above the diffusers with the highest air flow rates.

3.3. Manufacturer’s Clean Water Data

In order to estimate α factors from off-gas results, it is necessary to know the diffusers' clean water transfer rate in the tested configuration. The α factors can be calculated from the αSOTE measured in the off-gas analysis by dividing by the SOTE reported by the manufacturer at the same air flow rate per diffuser.

Figure 4 shows the clean water transfer efficiencies reported by EDI (Columbia, MO, 65202), the supplier of the diffusers. These tube diffusers are part of a family of offerings by EDI with two different diameters and several lengths (different materials are also available). Efficiency is estimated using the air flow rate per unit of active area (diffuser area passing bubbles – the ends of tube diffusers are generally not perforated for structural reasons).

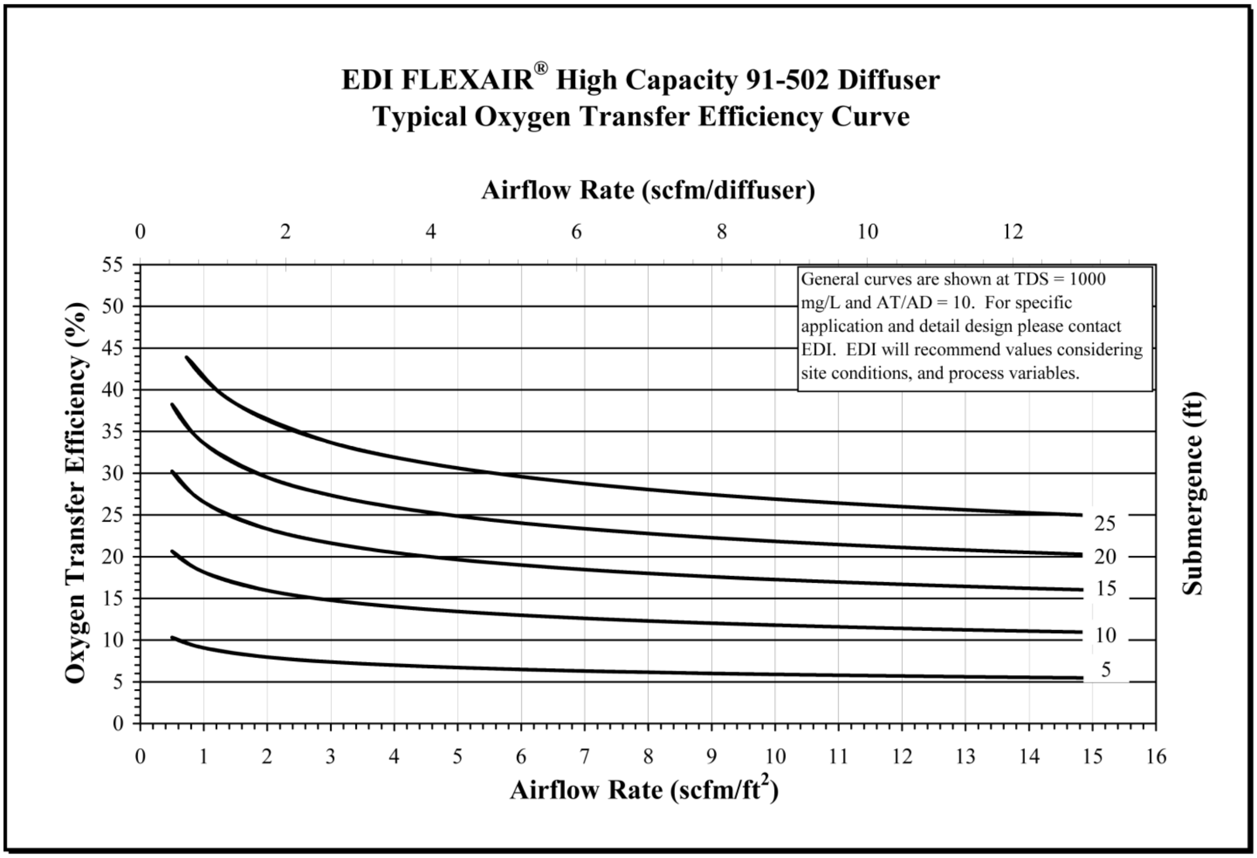


Figure 4. Clean water transfer efficiency data as a function of air flow rate per unit of active diffuser surface area (data supplied by EDI for EPDM diffusers in a spiral roll configuration). Transfer graphs are the same for a 62 and 91 mm diameter by 610 to 1003 mm long diffusers. Reported pressure drop range is 9 to 15 in. H_2O and recommended flow range is 4 to 13 scfm per diffuser. Active area for the 9 x 502 model is 1.3 ft^2. The average air flow rate measured in the test was 2.35 $scfm/ft^2$ corresponding to 17.8% at 12.4 feet submergence.

A general rule for fine pore diffuser systems is that they transfer 2% per foot of diffuser submergence. This generalization is a good first estimate but needs to be refined based on diffuser density and spacing. Greater diffuser density (diffuser active area per unit of tank floor area) will result in higher transfer efficiency. In this case the diffusers were retrofit on the existing coarse bubble air distribution system, which does not provide optimum spacing or density. These same diffusers would provide higher transfer efficiency in a full-floor coverage geometry.

4. RESULTS AND DISCUSSION

4.1 Off-Gas Tests

Testing began about 9 AM and continued to approximately 4 PM. The first test were performed on a Friday. Table 1 and Figure 5A show the testing results. Table 1 shows the OTE and αSOTE, along with the α factor, DO, flow rate per diffuser and oxygen uptake rate. The α factor is calculated from the αSOTE, which is measured by the analyzer and the SOTE that was reported by the manufacturer. Figure 5A shows the αSOTE and OTE separated by a forward slash (/) and the air flux in parenthesis. Dissolved oxygen profiles were measured at approximately 11 AM and are shown in Figure 6A. Table 2 and Figures 5B (OTE and αSOTE only) and 6B show the results from Monday, June 6 using the bucket hood.

The tests results and observations support two general findings. The first is an oscillating air flow rate. Apparently the blower is at a point on the curve where very small valve changes produce wide swings in air flow rate. This is often the case in fine pore retrofits of coarse bubble aeration systems, because a control valve, sized for much larger flow rate, is being positioned in a barely open position. Any small movement in the valve causes large changes in air flow rate. It is also possible that the blower control system needs tuning. The concept of DO control is quite simple, but in the authors' experience it is seldom performed well. Wide swings in air flow rate are often observed and the City of LA Tillman Plant was a prime example. The air flow rate would increase to 2.5 times the needed flow and then overshoot back to almost zero. The large swings in air flow rate impacted the test results, as will be shown later.

The second important observation is that the DO concentrations are excessive, especially in Tank 2 where DOs above 4 mg/L were present in many locations. The high DO may also be contributing to the excessive DO in the selector areas, which are not baffled. It is common practice to establish anoxic zones by turning off the air flow. Unfortunately this usually sets up a circulating liquid flow along the length of the tank. The surface of a fine pore aeration tank rises approximately 4 to 5 inches when the air is turned on. This means that there is a 4 to 5 inch water column pressure difference between aerated and unaerated zones. The resulting circulating flow carries high DO water into

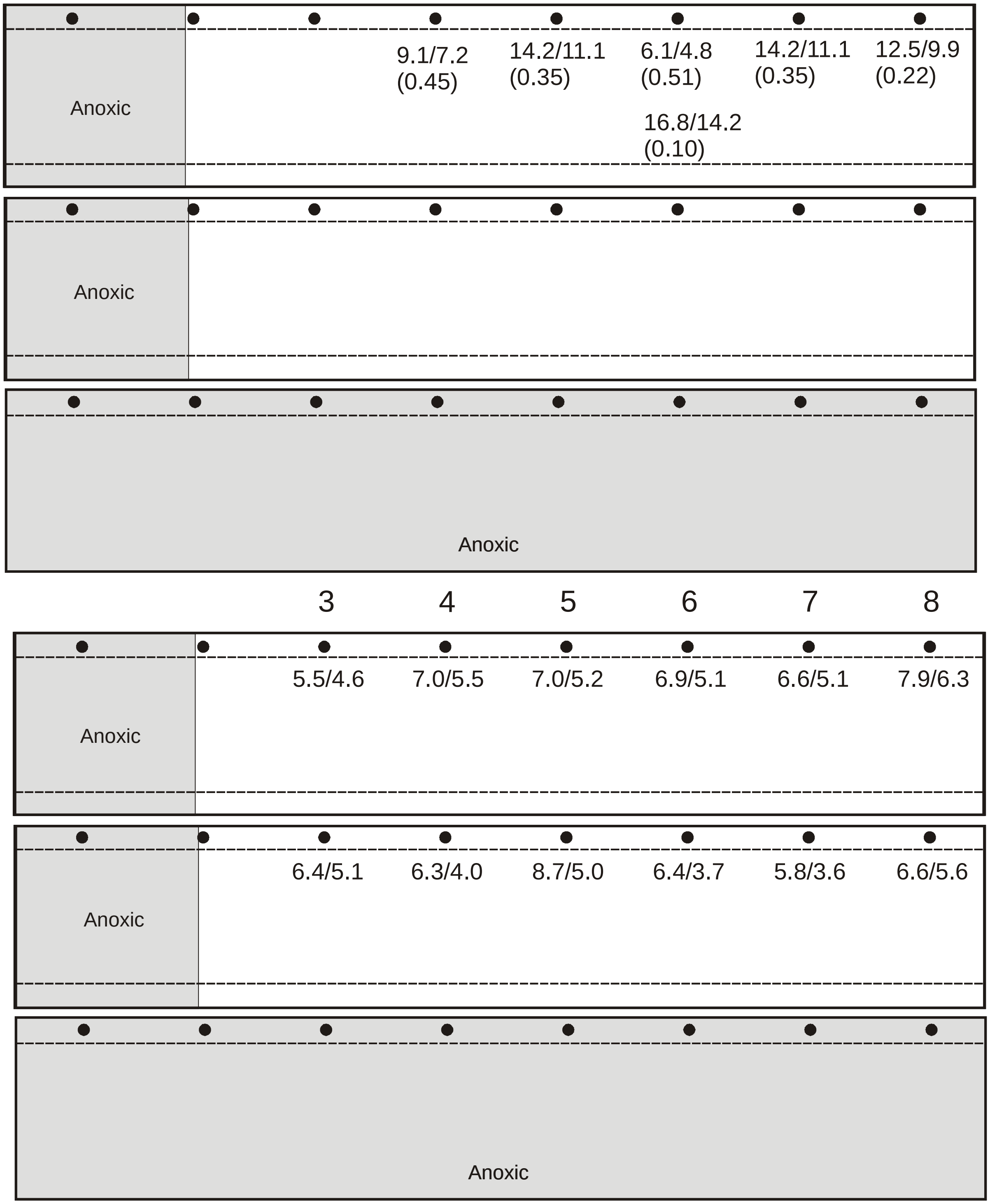


Figure 5A and 5B. The upper figure shows the off-gas test results for αSOTE, OTE and air flux (arranged as αSOTE/OTE and (air flux) for tests performed on 4/22/2011 using the large hood. Efficiencies in percentages and air flux in scfm/ft^2 of tank area. The lower figure shows only αSOTE and OTE.

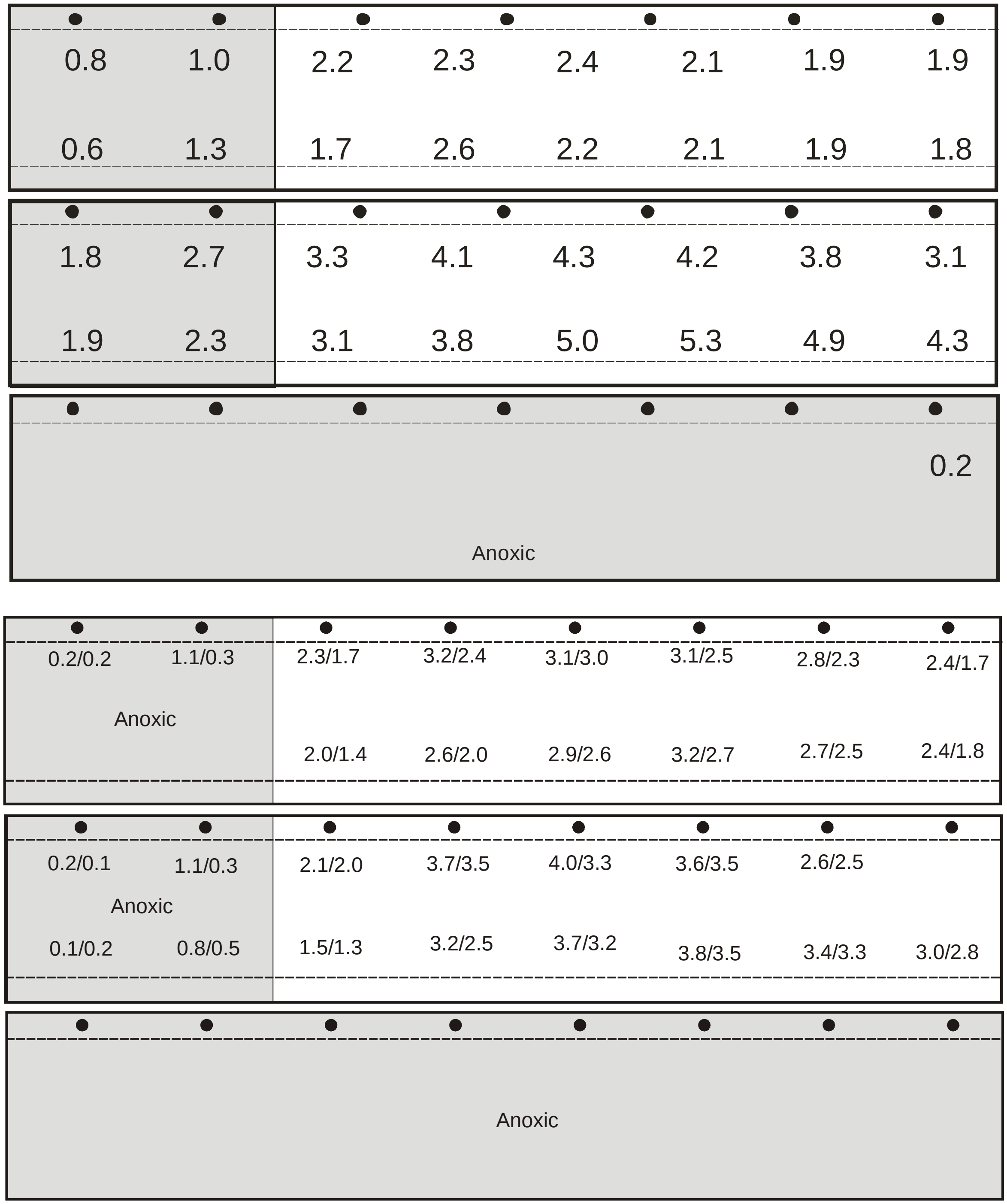


Figure 6A and 6B. DO profiles in mg/L. Measurements taken with a YSI Model 58 meter with stirrer type probe. Top figure measurements were taken on 4/22/2011 and measurements were approximately 4 ft below the surface, from 10 to 10:30 AM.. Lower figure measurements were taken on June 6 and include two positions , at the surface and five feet below the surface (surface/below the surface). The DO in the tanks is generally higher than the set point and the anoxic zones in Tanks 2 and 3 had measureable DO in all but one location. (0.1 mg/L).

the anoxic zones and keeps them from becoming truly anoxic. This problem is easily solved using baffles. The baffles need not be tight against the tank walls and bottom and should extend no more than a few inches below the liquid surface (extending the baffles above the surface will trap *nocardia*-form organisms and become a selector for *nocardia*-form).

Figure 7 shows the dependence on aeration on air flow rate. It also shows how variable the conditions are during short periods of time. This graph was created from off-gas results on 4/22/2011. The decline in efficiency with increasing air flow rate is "steep" which may contribute to DO control problems.

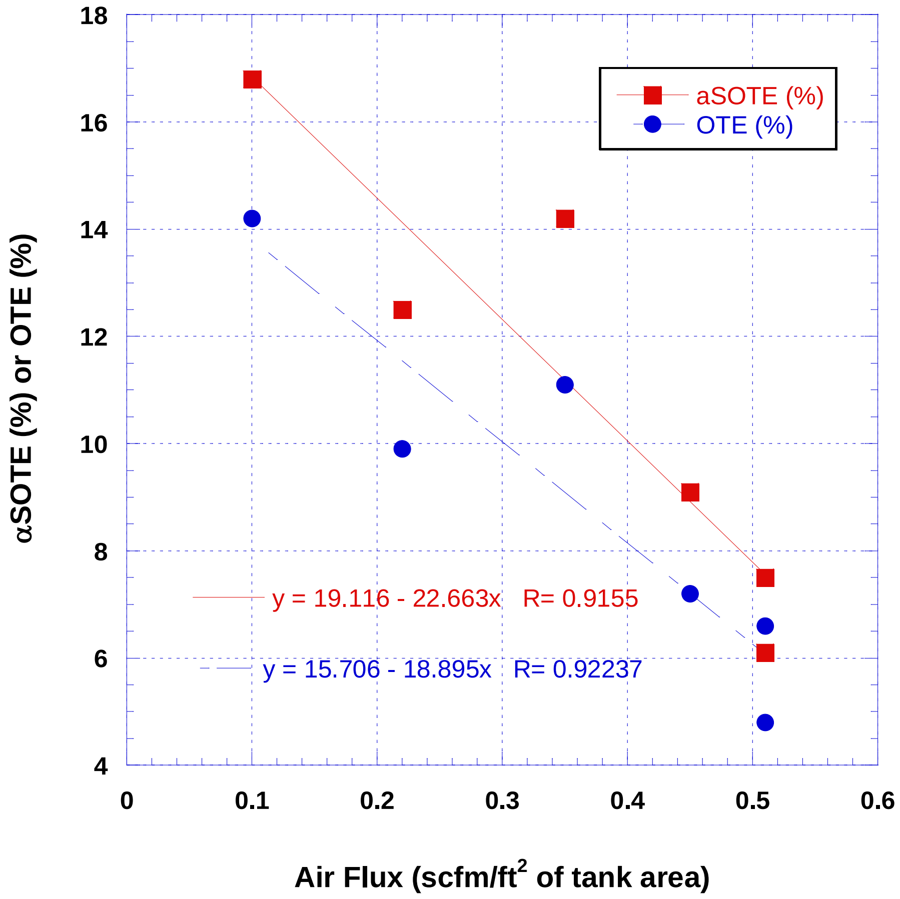


Figure 7. Transfer efficiency as a function of air flow rate per unit of tank area.

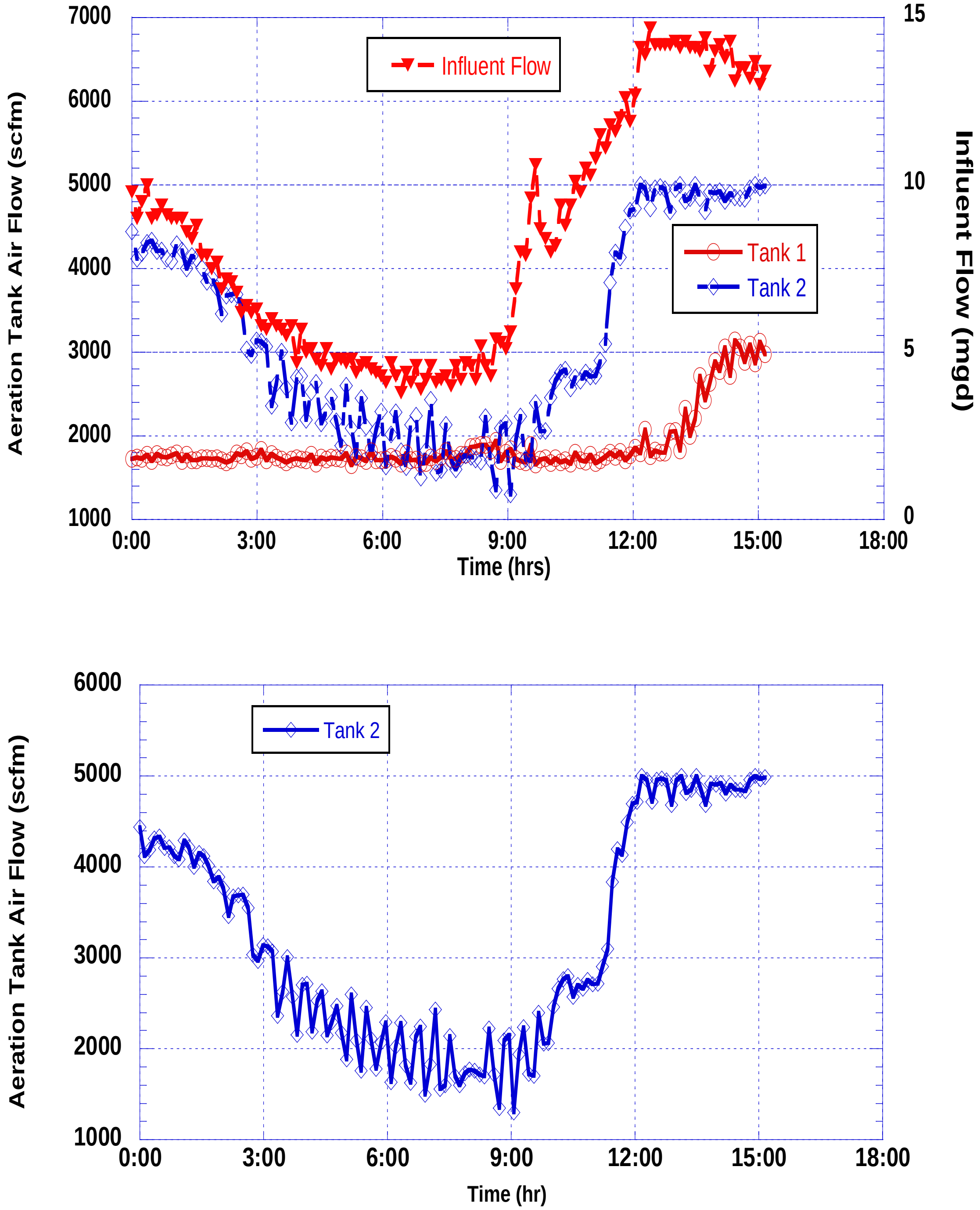


Figure 8A and 8B. Air flows to Tanks 1 and 2 and Influent wastewater flow versus time during the test. The bottom graph is just Tank 2 graphed slightly larger to illustrate oscillating flow rate. Also it appears that there is a limit, perhaps a controller limit, at 5,000.scfm. Generally at this time the DO in Tank 2 was above the set point and additional flow was not needed.

4.2 Comparison to Other Systems.

It is useful to compare this plant to other systems tested by the author. Figure 9 shows the results of approximately 100 off-gas tests conducted at 30 different treatment plants with a variety of types of fine pore diffusers. The diffuser submergence at this plant is 3.78 m and the average transfer efficiency is 9.9% for Tank 1 and will be lower in Tank 2. This converts to 2.6% αSOTE per meter. This is shown as the large black dot at 15 days SRT on Figure 9. This is the lowest transfer efficiency measured at this SRT and would be even lower if the efficiencies from Tank 2 could have been measured.

4.3 Alternative Diffuser System.

An alternative geometry as a full floor coverage system would greatly improve transfer rates and probably result in about 50% air savings. This combined with reductions in channel air flow rates might enable the plant to operate with only the small blowers, or to allow the large Roots blowers to be downsized (operated with a variable frequency drive or modified impeller size). The other alternative is to replace the smaller blowers with modern, high efficiency machines, sized for the new aeration system.

Appendix B contains two pictures of the surface of a high-density full floor coverage fine pore system and the same system during maintenance (dewatered) to show the diffuser piping. This system has a diffuser density of 4 At/Dt (area of the tank bottom to the total diffuser surface area, and has an SOTE of ~ 38% at 14 ft submergence, compared to existing system of about 21% . Notice how quiescent the surface becomes with distributed air.

Figure 10 shows a simple sketch of how an alternative system might look. There are two grids and two “downcomers” which should be equipped with air flow control valves. The two grids allow the air flow rate to be tapered. Tapering the air is important in order to match the declining oxygen uptake rate (OUR) typically observed in plug flow aeration tanks. Also two control points are needed to adjust air flow rate caused by the differing pressure drop in the pipe lines. Fine pore diffusers are more sensitive to pressure drop than coarse bubble systems and control valves are needed to maintain proper air distribution.

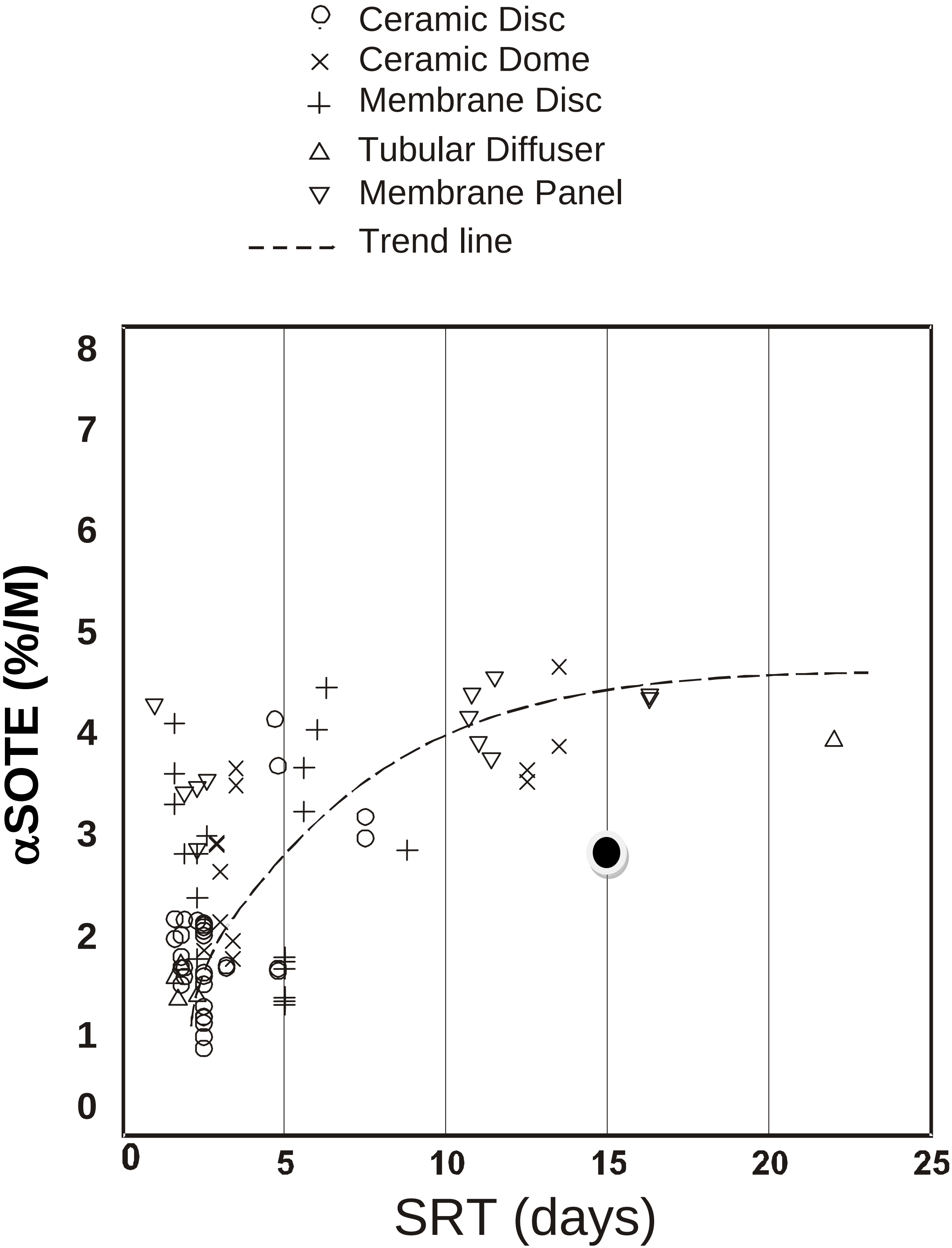


Figure 9. Comparison with other aeration test as a function of SRT. Large black dot shows current test results.

An alternative is to construct 7 grids with each tied to the existing swing arm piping In the authors' experience this is a poor choice. Seven control valves would be needed to taper the air flow rate, which creates additional expense if automatic control is to be used. Valves used on swing arms are not designed for frequent movement and best function as "on or off" valves. Additional DO probes would be necessary to facilitate automatic control.

A successful technique which reduces the control expense and controller "hunting" is to use control loops on the two down comers with low gains to produce slow response, and a second loop on the single valve for the entire tank, which performs most of the air flow modulation. The downcomer valves may only need to change position once between high and low loading periods of the day. Two DO probes per tank are needed for optimal performance. Tube or disc diffusers can be used, although disc diffusers are more common for full floor coverage installation.

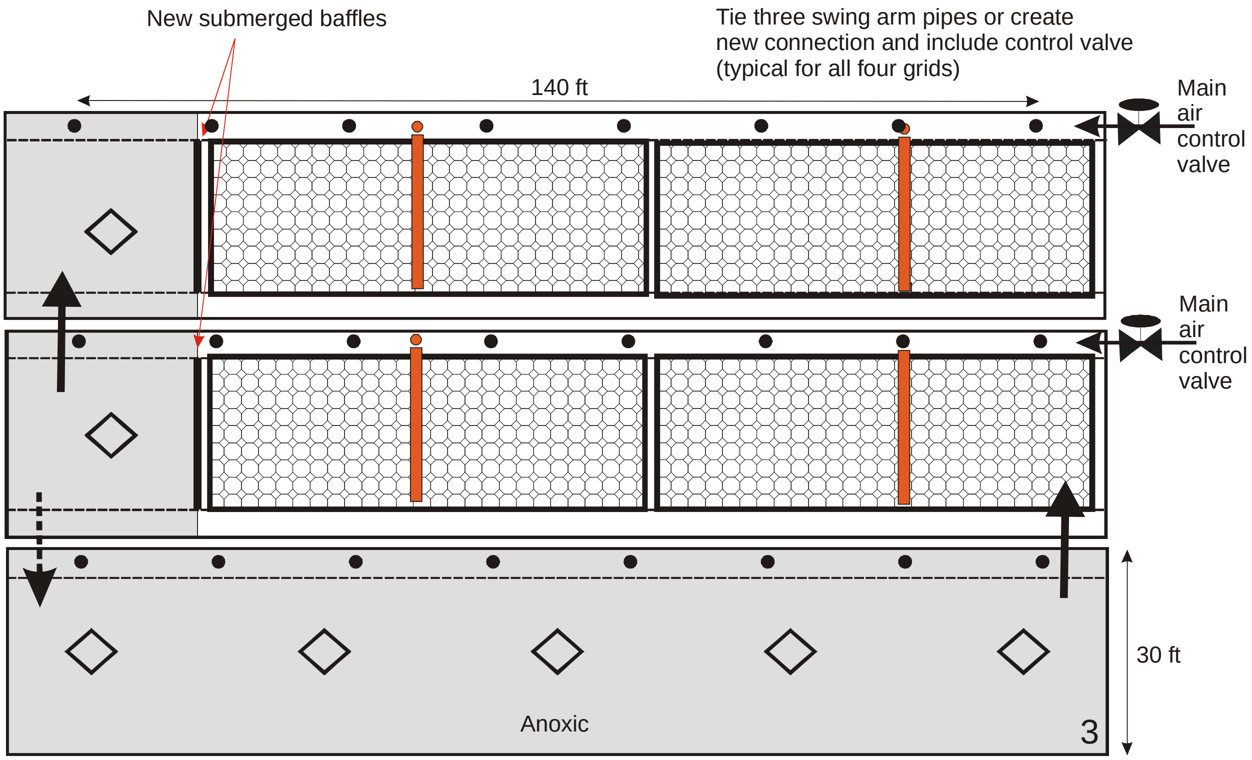


Figure 10. Possible full floor aeration system with two grids per tank.

The DO profile shows that the second anoxic zone is not fully anoxic, at least during the period of the profile measurement (~11:00 AM, after the large Roots blower was started). An analysis of the effectiveness of the second anoxic zone should be made. If it is retained, baffles should be used to isolate the zone from unwanted aeration, which may allow the zone to be down sized. Also the swing arm valves do not completely shut off the air and some air flow could be seen in the anoxic zone in Tank 1. Alternatively the anoxic zone could be eliminated, perhaps without much degradation of the denitrification efficiency.

The system air pressure will increase for a full floor configuration. The depth of submergence, which is presently 12.4 ft, may be increased to position the diffusers closer to the tank bottom. The greater submergence requires greater blower discharge pressure but not more power, since the increased depth also results in higher transfer efficiency. The increase in efficiency offsets the increased blower power. The more important question will be if the blowers can accommodate the increased pressure, and this will require an analysis of the blower curves. The air flow schematics shown in Appendix D show a number of orifice plate flow meters, which have high permanent pressure drop, and could be replaced with Annubars or hot-wire anemometers, which both have lower pressure drop.

Large amounts of foam, resembling *Nocardia*-form was observed on all three visits to the treatment plant. The situation is probably made worse by the tendency of the tanks to trap foam. Tanks 1 and 6 have open exit weirs which allow foam to flow out, but the weirs between Tanks 1 and 2 and 2 and 3 (also presumably in Tanks 4 and 5 and 5 and 6) are good foam traps. A full floor fine pore diffuser system will have less surface turbulence and will make foam management more difficult. If a new aeration system is installed, it would provide good opportunity to modify tank details to allow foam to flow through the aeration tanks.

5. **REFERENCES**

1. ASCE, (1984, 1992, 2006) ASCE Standard: *Measurement of Oxygen Transfer in Clean Water*, ISBN 0-87262-430-7, New York, NY.
2. ASCE(1997*)* ASCE *Standard Guide Lines for In-Process Oxygen Transfer Testing*, ISBN 0-7844-0114-4, New York, NY.
3. Kaliman, A., Rosso, D., Leu, S-Y., and M.K. Stenstrom, M.K. (2008) “Fine-pore aeration diffusers: Accelerated membrane ageing studies,” *Wat. Research*, **42**(1-2), 467-475.
4. King, H.R. "Mechanics of Oxygen Absorption in Spiral Flow Aeration Tanks," *Sewage and Industrial Wastes*, **27**(8), 894-908, 1956.
5. Morgan, P.F. and Bewtra, J.K., Air Diffuser Efficiencies, *Sewage Works Journal*, **32**(10), 1047-1059, 1960.
6. Redmon, D.T., Boyle, W.C., and Ewing. L. (1983) “Oxygen Transfer Efficiency Measurements in Mixed Liquor Using Off-gas Techniques,” *JWPCF*, **55**(11), 1338-1347.
7. Rosso, D., R. Iranpour and Stenstrom, M.K. (2005) “Fifteen Years of Off-Gas Transfer Efficiency Measurements on Fine Pore Aerators: Key Role of Sludge Age and Normalized Air Flux,” *Water Environment Research*, **77**(3) 266-273.
8. Rosso, D., Libra, J.A., Wiehe, W. and Stenstrom, M.K. (2008) “Membrane Properties Change in Fine-Pore Aeration Diffusers: Full-Scale Variations of Transfer Efficiency and Headloss,” *Wat. Research*, **42**(10-11), 2640-2648.
9. Rosso, D and Stenstrom, M.K. (2005) “Comparative Economic Analysis of the Impacts of Mean Cell Retention Time and Denitrification on Aeration Systems,” *Wat. Research*, **39**(16), 3773-3780.
10. Stenstrom, M.K. and Gilbert, R.G. (1981) “Effects of Alpha, Beta and Theta Factors in Design, Specification and Operations of Aeration Systems,” *Water Research*, 15(6), 643-654.
11. Stenstrom, M.K. and Masutani, G. (1990a) “Fine Pore Diffuser Fouling - the Los Angeles Studies,” UCLA Engr. Report No. 90-02, Los Angeles, CA.
12. Stenstrom, M.K. (1990b) “Upgrading Existing Activated Sludge Treatment Plants with Fine Pore Aeration Systems,” *Water Science and Technology*, **22**(7/8), 245-251.
13. US. EPA (1983) *Design Manual - Fine Pore Aeration Systems*, Risk Reduction Laboratory, Cincinnati, Ohio, EPA/625/1-89/023.

APPENDIX A. OFF-GAS ANALYSIS TECHNICAL DESCRIPTION

One of the problems with aerobic wastewater treatment process design is the correct specification of aeration capacity. A variety of techniques exist for estimating the oxygen transfer capacity of an aeration system. Methods for estimating transfer can generally be divided into three categories:

- Clean water testing and conversion to field rates with alpha, beta, and theta conversion factors.
- Dirty water testing using methods to account for the biological consumption of oxygen during the transfer test.
- Material balance methods which attempt to determine difference in input and outputs of oxygen consuming material.

All of these methods have advantages and disadvantages. When using clean water test results it is very difficult to accurately estimate the alpha factor (ratio of mass transfer coefficient in dirty water to its value in clean water). Dirty water testing requires accurate estimation of oxygen consumption rate, which is often very difficult, especially in oxygen limiting conditions, which occur in overloaded treatment plants. Material balance methods require long-term knowledge of process operating conditions such as sludge wasting rate, and are susceptible to error from sludge settling in the aeration basin or stripping of volatile oxygen consuming compounds.

A technique which has none of the above shortcomings is off-gas analysis. This method requires the capture of a representative sample of the gas, which exits the aeration basin surface, and analysis of this gas for oxygen, carbon dioxide, and water vapor content. By knowing the flow rates of gas entering and exiting the liquid, the mass transfer efficiency can be calculated. If flow rates are not known, the mass transfer efficiency can still be determined by knowing the molar percents of the reacting or changing gas constituents (oxygen, carbon dioxide, and water vapor) and assuming that the inert gas constituents (nitrogen, argon) remain constant. It must be further assumed that the transfer at the fluid surface and the atmosphere is negligible when compared to the transfer caused by the aeration system, and that steady state conditions exits during the test. Both assumptions are very good for the wastewater treatment systems.

The concept of off-gas analysis is not new and was originally described in 1939 by Sawyer and Nichols (1939). A number of later investigators continued the development of off-gas analysis, including Hover et. al. (1954), Pauling et al (1968), Prit and Callow (1958) and Downing (1960). More recently Conway and Kumke (1966) and Leary et al. (1968) have used off-gas analysis. The ASCE/EPA subcommittee on oxygen transfer testing asked Ewing Engineering (Redmon et al., 1983) to further develop the technique. Their results reported at the 1982 WPCF meeting show that the off-gas technique is an accurate and precise way of estimating aeration efficiency under process conditions. New developments which make this method more precise are advances in oxygen analyzers, and the use of large off-gas collection hoods which capture more representative samples.

Off gas analysis can be used for any subsurface system regardless of the oxygen uptake rate and process conditions. Efficiencies of oxygen-limited systems can also be determined, although the transfer rate may be different than the transfer rate under normal operation. It has been documented that alpha factors vary greatly with such conditions (Stenstrom and Gilbert, 1981).

THEORY OF ANALYSIS

To determine oxygen transfer efficiency using off-gas analysis, a mass balance must be performed on the gas entering and exiting the liquid. The following description is provided, and is based largely on the analysis by Redmon et al. (1982). If the flow rates of gas entering an exiting the fluid are known, then the following mass balance can be made:

$$V_G \rho \frac{d\overline{Y}}{dt} = \rho(q_i Y_R - q_o Y_{og}) - K_L a(C^*_\infty - C)V \tag{1}$$

where:

ρ density of oxygen at temperature and pressure of gas flow,

q_i, q_o = total volumetric gas flow rates of inlet and outlet gasses,

Y_R, Y_{og} = mole fractions (equivalent to volumetric fractions) of oxygen in the inlet and exit gasses,

$K_L a$ = volumetric oxygen transfer coefficient,

C^*_∞ = equilibrium dissolved oxygen concentration in the test liquid at the given conditions,

C = oxygen concentration,

V = liquid volume, and

V_G = gas hold-up volume.

At steady state the equation reduces to:

$$\rho(q_i Y_R - q_o Y_{og}) = K_L a(C^*_\infty - C)V \tag{2}$$

The left hand side of equation 2 is the amount of oxygen transferred as determined from the change in oxygen mass and flow rate of the inlet and outlet gas streams. The right hand side of equation 2 is the familiar "K rate" based upon the mass transfer coefficient and driving force.

Since it is often difficult to measure the entering gas flow rate to an aeration system, a procedure which does not rely on gas flow rates is needed. If one assumes that the inert portions of the entering gas stream do not change, a mole fraction approach can be developed which does not require gas flow rate. This assumption means that the nitrogen, argon, and inert trace gasses do not change as they pass through the aeration system. The new technique (Redmon et al., 1982) relies upon this assumption to calculate oxygen transfer efficiency (OTE).

OTE expressed as a fraction, can be derived as follows:

$$\text{OTE} = \frac{\text{mass } O_2 \text{ in} - \text{mass } O_2 \text{ out}}{\text{mass } O_2 \text{ in}} \tag{3}$$

$$= \frac{G_i(M_o / M_i)MR_{o/i} - G_i(M_o / M_i)MR_{og/i}}{G_i(M_o / M_i)MR_{o/i}} \tag{4}$$

$$= \frac{MR_{o/i} - MR_{og/i}}{MR_{o/i}} \tag{5}$$

where:

G_i = mass rate of inerts, which is constant (by assumption) in both the inlet and off-gas streams

$M_o M_i$ = molecular weights of oxygen and inerts, respectively

$MR_{o/i}, MR_{og/i}$ = mole ratio of oxygen to inerts in the inlet and off-gas streams

The mole ratio of oxygen to inerts is calculated by subtracting the mole fractions of oxygen, carbon dioxide and water vapor, as follows:

$$MR_{o/i} = \frac{Y_R}{1 - Y_R - Y_{CO_2(R)} - Y_{W(R)}} \tag{6}$$

$$MR_{og/i} = \frac{Y_{og}}{1 - Y_{og} - Y_{CO_2(og)} - Y_{W(og)}} \tag{7}$$

where:

$Y_{CO_2(R)}, Y_{CO_2(og)}$ = mole fractions of CO_2 in the reference gas(R), or off-gas (og)

$Y_{W(R)}, Y_{W(og)}$ = mole fractions of water vapor in the reference gas (R) and off-gas (og)

The value of Y_R is the mole ratio of oxygen in air, and can be calculated by subtracting the humidity from the known (handbook) mole fraction of oxygen in dry air as follows:

$$Y_R = 0.2095(1.-Y_{W(R)}) \qquad (8)$$

The mole fraction of oxygen in the off-gas must be measured experimentally, as well as the CO_2 and water vapor mole fractions. For early Ewing Mark V devices the CO_2 was measured with an Orsat, which measures the CO_2 as a volume percent. The sample off-gas is dried in the later version of the Mark V instrument, which means Y_W is zero. The oxygen mole fraction is measured with a Teledyne Model 320B analyzer, which provides a signal proportional to mole fraction, and can be calibrated directly at the pressure of the inlet air. In later instruments the CO_2 is absorbed with sodium hydroxide which removes it from the calculations. The CO_2 and water vapor are also removed from the reference gas, since it flows through the absorber column.

FLOW WEIGHTED AVERAGING

The single value of OTE obtained from a single analysis represents the transfer at a single "point" in the aeration basin. The size of the point is equivalent to the size of the collection hood. In general, larger hoods provide more representative samples of the OTE of the entire tank.

If only a few hood locations are used, erroneous results may occur. For example, if the hood is located over a break in an air pipe line, very low OTEs will be measured. To obtain a representative single average value of OTE for an aeration tank, it is necessary to sample many locations and calculate an appropriate average. In the recent EPA sponsored research project (US EPA, 1989), a protocol was developed which required sampling at least 2% of the tank surface area.

To calculate an average OTE, the individual readings must be averaged. Since aeration basins are usually tapered, each hood location generally has a different gas flow rate. If the gas flow rate at each hood location is known, a flow weighted average can be calculated. For this reason, the Ewing instruments include gas flow rate meters (rotameters) for measuring hood airflow rate, and a manometer to indicate hood pressure. When the hood pressure is stable, gas flow rate indicated by the instrument is equal to the hood collection flow rate.

In designing an off-gas experiment it is also necessary to select hood locations that are representative of specific areas of the tank. This is especially important if highly tapered aeration tanks, or tanks with irregular geometries, are being tested. To calculate a tank average, equation 9 is used:

$$\overline{OTE} = \frac{\sum_{i=1}^{m} A_i Q_i OTE_i}{\sum_{i=1}^{m} A_i Q_i} \qquad (9)$$

where

i = hood location (sample number)

A_i = area associated with hood location i,

Q_i = air flux associated with hood location i (equals the gas flow rate measured by the analyzer divided by hood area),

OTE_i = oxygen transfer efficiency measured at location i, and

$\overline{OTE}$ = overall average OTE.

This equation represents a flow-weighted, area-weighted average OTE. In cases where the tank geometry is uniform, such as a fine pore, full floor coverage aeration tank with equal sized grids, equal areas can be incorporated into the test design, and the area terms in equation 9 cancel.

If other indications of gas flow rate exist, they can be compared to the gas flow rate indicated by the instrument. The denominator of equation 9 represents the entire tank gas flow rate. If reliable plant instrumentation exists, one should expect the hood and plant flow rates to correspond very closely. The ability to accurately match the two flow rates in full-scale aeration tanks has been demonstrated (Stenstrom and Masutani, 1990). One should not expect the air flux at each hood location to match the air flux indicated by the plant instrumentation; however, if the plant instrumentation is accurate, the average airflow rate indicated by the instrument and plant instrumentation should agree.

In special cases, such as testing in pilot columns, the entire off-gas flow can be captured. In this case, no flow weight averaging is required.

CORRECTION TO STANDARD CONDITIONS

It is useful to calculate the OTE of the aeration at standard conditions, insofar as this is possible. If the mixed-liquor dissolved oxygen, temperature and TDS are measured at the same time OTE is measured, and if the equilibrium DO concentration (C^*_∞) is known, it is possible to calculate αSOTE. The correction is made in the same way as clean water data are corrected to standard conditions, as follows:

$$\alpha SOTE = \frac{OTE\ C^*_{\infty 20}}{(\Omega \beta C^*_{\infty T} - DO)\Theta^{T-20}} \qquad (10)$$

where:

$C^*_{\infty 20}$ = equilibrium DO concentration at 20°C, 760 mm barometric pressure, zero salinity,
$C^*_{\infty T}$ = equilibrium DO concentration at temperature T, 760 mm barometric pressure, zero salinity,
Ω = barometric pressure correction factor,
β = salinity correction factor,
Θ = temperature correction factor (= 1.024 for the ASCE Standard, 1991),
DO = operating DO concentration, and
T = temperature, °C

The pressure correction factor Ω accounts for the effect of non-standard barometric pressures. It is calculated as follows for basins less than 6.1 m (20 ft) deep:

$$\Omega = \frac{P_b}{P_s} \qquad (11)$$

where:

P_b = barometric pressure during the test, psia

P_s = standard atmospheric pressure 14.7 psia at 100% relative humidity

For deeper tanks a more elaborate procedure is required, as follows:

$$\Omega = \frac{P_b + 0.007\gamma_w d_e - P_{vT}}{P_s + 0.007\gamma_w d_e - P_{vT}} \qquad (12)$$

where:

γ_w = specific weight of water at temperature T, lb/ft^3,
P_{vT} = saturated vapor pressure of water at temperature T, psia, and
d_e = effective saturation depth, at infinite time, ft

The effective depth, d_e, is defined as the depth of water under which the total pressure (hydrostatic plus atmospheric) would produce a saturation concentration equal C^*_∞ for water in contact with air at 100% relative humidity. The value of d_e can be calculated from clean water test data, as follows:

$$d_e = \frac{\left[\frac{C_\infty^*}{C_s} \left[P_s - P_{vT} \right] - P_b + P_{vT} \right]}{\gamma_w 0.007}$$

(13

)

where:

C_S = oxygen saturation concentration at temperature T (handbook value)

Generally for fine pore diffuser systems that are mounted no more than 10% of the overall water depth above the tank floor, the value of d_e will range between 21 and 44% of the overall water depth (US EPA, 1989).

If the standard oxygen transfer efficiency (SOTE) of the aeration systems is known from clean water tests or from manufacturer's data, the α factor can be calculated as follows:

$$\alpha = \frac{\alpha \mathrm{SOTE}}{\mathrm{SOTE}} \qquad (14)$$

The α factor is the ratio of process water to clean water mass transfer coefficients K_La. It is generally necessary to know its value when designing aeration systems. Its measurement is often the goal of process water testing. A new factor, F, was introduced in 1989 in the US EPA design manual (1989). This factor represents the state of fouling of fine pore diffusers. Generally, fine poor diffusers foul and the α factor calculated after several years of operation, especially without cleaning, can be 50% of the new α factor. (Stenstrom and Masutani, 1990). When testing aeration systems that have been in operation for any considerable period of time, the αFSOTE is determined when using equation 10.

To calculate overall, average, α F, or α SOTEs, equation 9 is used by replacing OTE with the desired parameter.

APPENDIX A REFERENCES

ASCE (1991). *ASCE Standard: Measurement of Oxygen Transfer in Clean Water*, ISBN 0-87262-430-7, New York, NY.

Conway, R.A. and Kumke, G.W. (1966). "Field Techniques for Evaluating Aerators," *Journal of the Sanitary Engineering Division*, ASCE, Vol 92, SA2, p21.

Downing, A.L. (1960). "Aeration in the Activated Sludge Process," *Institution of Public Health Engineers*, Vol 59, pp 80.

Hoover, S.R., Jasewicz, L. and Porges, N. (1954). "Measurement of Oxygen Transfer ," *Inst. and Autom.*, Vol 27, p 774.

Leary, R.D., Ernest, L.A. and Katz, W.J. (1968). "Effect of Oxygen Transfer Studies of Seven Diffuser Systems," *Journal of the Water Pollution Control Federation*, Vol 40, pp 1298.

Pauling, L., Wood, R.E., Sturdivant, J.H. (1968)."An Instrument for Determining the Partial Pressure of Oxygen in a Gas," *Journal of the American Chemical Society*, Vol 68, p 795.

Prit, S.J. and Callow, D.S. (1958). "Exocellular Product Formation by Microorganisms Continuous Culture I. Production of 2:3-Butanediol by Aerobacter Aerogenes in a Single Stage Process," *Journal of Applied Bacteriology*, Vol 21, pp 188.

Redmon, D.T., Boyle, W.C., and Ewing, L. (1983) Oxygen Transfer Efficiency Measurements in Mixed Liquor Using Off-gas Techniques, *Journal of Water Pollution Control Federation*, v.55, pp. 1338-1347.

Sawyer, C.N., and Nichols, M.S. (1939). "Activated Sludge Oxidations -I Effect of Sludge Concentration and Temperature on Oxygen Utilization," *Sewage Works Journal*, Vol. 11, p 52.

Stenstrom, M.K., and Gilbert, R.G. (1981). "The Effect of Alpha, Beta, and Theta Factors on the Design, Specification an Operation of Aeration Systems," *Water Research*, Vol 15, pp 643-654.

Stenstrom, M.K. and Masutani, G. (1990). "Fine Pore Diffusers Fouling: The Los Angeles Studies," UCLA Engr. 90-02, January 1990.

U.S. EPA (1989). *Design Manual - Fine Pore Aeration Systems*, Risk Reduction Engineering Laboratory, Cincinnati, OH, EPA/625/1-89/023.

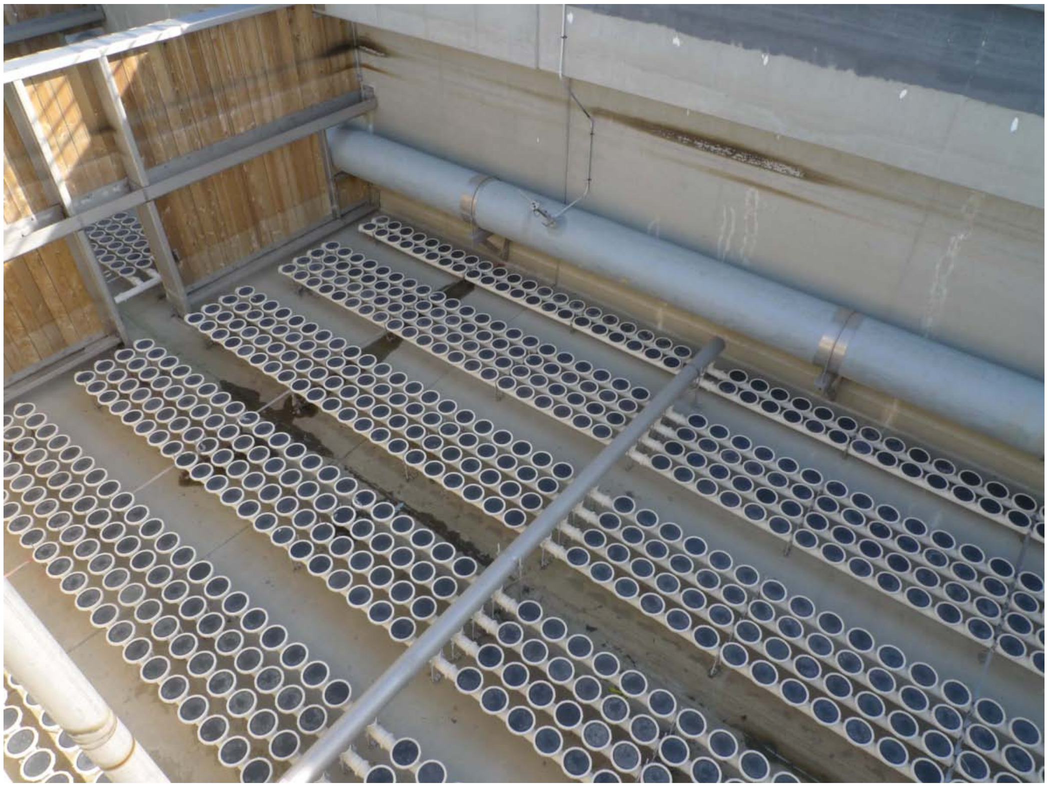
(Appendix A revised 10-2010)

APPENDIX B PHOTOGPAPHS OF THE TESTING

Picture 1 (top) showing off-gas hood (white) and analyzer near the effluent end of Tank 1. Tie down ropes and off-gas hose visible.
Picture 2 (bottom) showing spiral roll action and surface foam in Tank 2.

Picture 3 showing surface boil above swing arms and surface foam in Tank 2.

Picture 4 (top) showing off-gas analyzer, author and bucket hood on 1.5 in, diameter PVC pipe. **Picture 5** (bottom) showing a close up of the bucket hood.



Picture 6 (top) showing surface agitation of a high density full floor coverage fine pore aeration tank. **Picture 7 (bottom)** showing diffuser arrangement for the same tank. This is a high density disc system. The MLSS recirculation pipe and baffle are in the background.

Pictures 8 (top) and 9 (bottom) showing swing arms with fine pore tube diffusers. Diffusers removed in pairs to clear hand rails when the swing is fully retracted to the wall.

APPENDIX C. DATA SHEETS

Summary Section for Off-gas Analysis

Tapia April 22, 2011

Mole Fraction	(O2)	0.2095	Hood Area	(ft2)	23.3333333	Tank SWD (ft)	14.1
Mole Ratio	(O2/inert	0.2650	Actual Bar	Pres (in hg)	29.92	Diffuser Sub (ft)	12.4
Ref Barometric	Pres (in h	29.92	Hood 2 Area	(ft2)			
Theta		1.024					

Position	Comments	Station or Test	Ref Vol (volts)	Off-G Vol (volts)	H2O Temp (deg C)	DO (mg/L)	Beta	Off-gas Temp (deg F)	Rota 1 Reading (small)	Rota 2 Reading (big)	Roto Temp Correction	M Fraction Off-gas	M Ratio Off-gas	OTE (%)	C* inf T (mg/L)	aSOTE (%)	C* inf 20 (mg/L)
3N	Tank1		1.000	0.942	20.7	2.00	0.99	75	0	95	0.995	0.197	0.246	7.23	10.02	9.08	10.12
4N	Tank1		1.001	0.948	20.7	1.20	0.99	78	0	110	0.992	0.198	0.248	6.61	10.02	7.54	10.12
4S	Tank1		0.993	0.878	20.7	1.50	0.99	78	87	0	0.992	0.185	0.227	14.21	10.02	16.79	10.12
5N	Tank1		1.001	0.963	20.7	2.20	0.99	77	0	110	0.993	0.202	0.252	4.75	10.02	6.13	10.12
6N	Tank1		1.017	0.926	20.7	2.20	0.99	77		70	0.993	0.191	0.236	11.06	10.02	14.25	10.12
7N	Tank1		0.999	0.919	20.7	2.00	0.99	77	205	0	0.993	0.193	0.239	9.92	10.02	12.46	10.12

Flow Weighted Average

Position	Flux*Test Area	OTE	aSOTE	Alpha	OUR
3	460	3324	4175	241	15814
4	460	3038	3467	205	16223
5	460	2187	2818	167	11688
6	460	5086	6554	357	18797
7	460	4563	5732	293	10502
Sum	2300	18199	22746	1263	73025
Avg		7.9	9.9	0.55	31.7

Tapia April 22, 2011

Position	**Tank Distance**	**OTE**	**αSOTE**	**α**	**DO**	**Air Flux**		**O2 Uptake**
	(ft)	(%)	(%)		(mg/L)	(scfm/ft2)	(scfm/diff)	(mg/L-hr)
3	50	7.2	9.1	0.52	2.0	0.45	3.64	34.4
4	70	6.6	7.5	0.45	1.2	0.51	3.64	35.3
5	90	4.8	6.1	0.36	2.2	0.51	3.64	25.4
6	110	11.1	14.2	0.78	2.2	0.35	3.64	40.9
7	130	9.9	12.5	0.64	2.0	0.22	3.64	22.8
	Avg	**7.9**	**9.9**	**0.55**	**1.9**	**0.41**	**3.64**	**31.7**

Alpha	SOTE (%)	P Corr (ratio)	Abs T (deg K)	Roto Total Gas Flow (scfm)	Roto1 (scfm)	Roto2 (scfm)	Diffusers per Grid	Test Area (ft2)	Grid Area (at surface)	Diffuser Dens (/ft^2)	Analyzer Air Flux (scfm/ft2)	Plant Air Flux (scfm/ft2)	Analyser Air Flow/Diffuser (scfm/ft2)	Plant Air Flow/Diffuser (scfm/ft2)	Plant Air Flow (by analyzer) (scfm)	Plant Air Flow (plant instruments) (SCFM)	O2 Uptake Rate (mg/L-hr)
0.52	17.3	1.1145	293.7	10.5	0.0	10.5	65.0	240	480	0.27	0.45	0.54	2.56	3.64	1514	1800	34.4
0.45	16.9	1.1145	293.7	11.8	0.0	11.8	65.0	240	480	0.27	0.51	0.54	2.87	3.64	1699	1800	35.3
0.72	23.3	1.1145	293.7	2.4	2.4	0.0	65.0	240	480	0.27	0.10	0.54	0.58	3.64	345	1800	15.4
0.36	16.9	1.1145	293.7	11.8	0.0	11.8	65.0	240	480	0.27	0.51	0.54	2.88	3.64	1701	1800	25.4
0.78	18.4	1.1145	293.7	8.2	0.0	8.2	65.0	240	480	0.27	0.35	0.54	1.99	3.64	1176	1800	40.9
0.64	19.6	1.1145	293.7	5.1	5.1	0.0	55.0	240	480	0.23	0.22	0.54	1.46	3.64	732	1800	22.8
																	29.0
	18.7										0.41	AVG	2.35				
											1364.64						

New diffuser assumptions

Operations documents 65 tubes per swing exept at the far northern ends which have 55

Diffusers are 91 x 502. Assume 91 mm diameter by 502 long with 2 inchs or 50 mm unpunched at the ends.

Area = 0.13 m2

1.39 (EDI says 1.3, go with 1.3 ft2)

Diffuser area per swing = 55 *1.3 84.50 ft2

At the end 55 diffusers 71.50

APPENDIX D ADDITIONAL PLANT INFORMATION

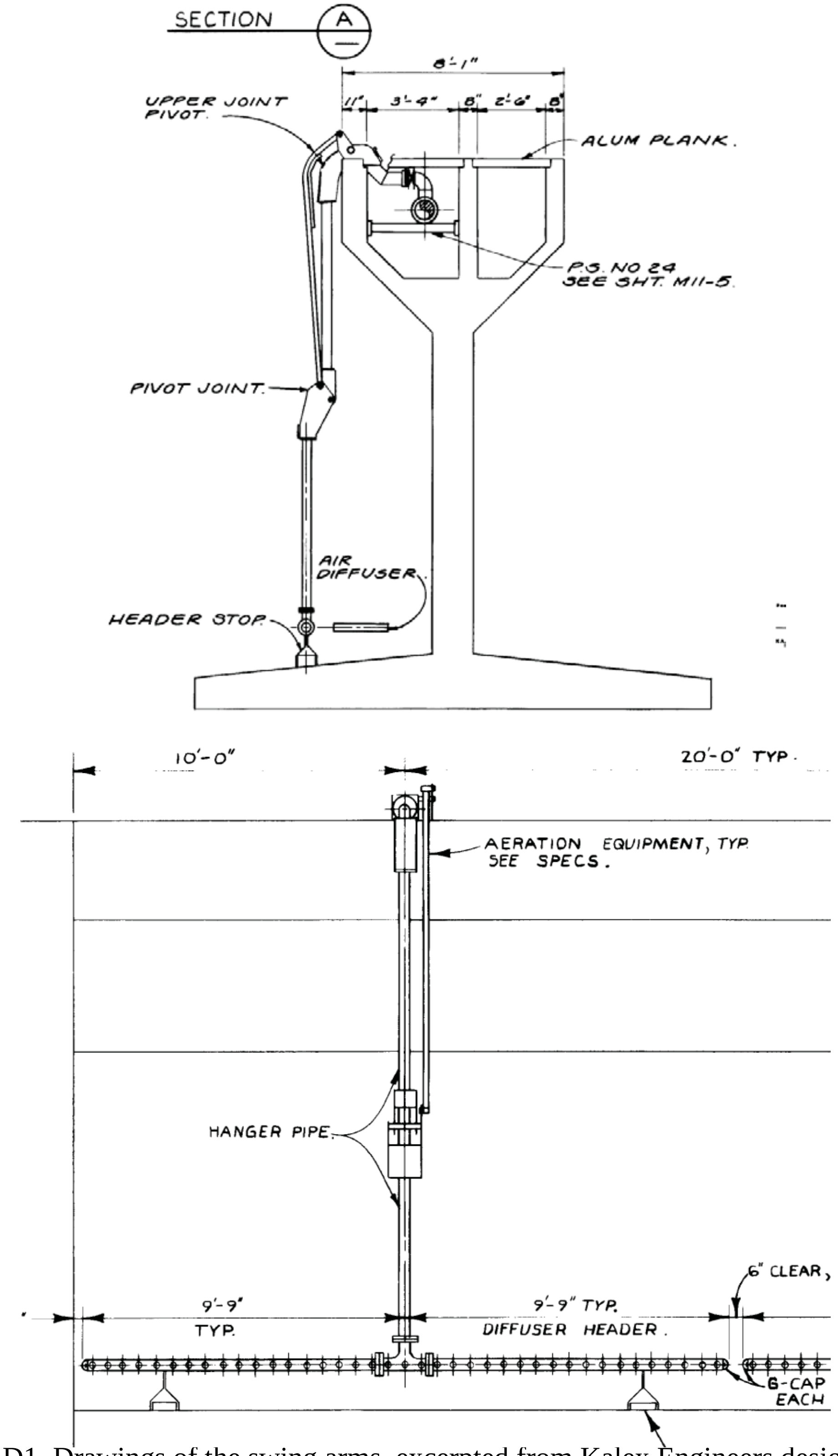


Figure D1. Drawings of the swing arms, excerpted from Kalex Engineers design drawings, dated 8-7-1987. Not to scale. See original drawings for more information. Side water depth is approximately 14.1 ft and diffuser submergence is approximately 12.4 ft. Original design envisioned diffusers on one side of the swing. Notice that the “Y” is helps create a circulating mixed-liquor flow.

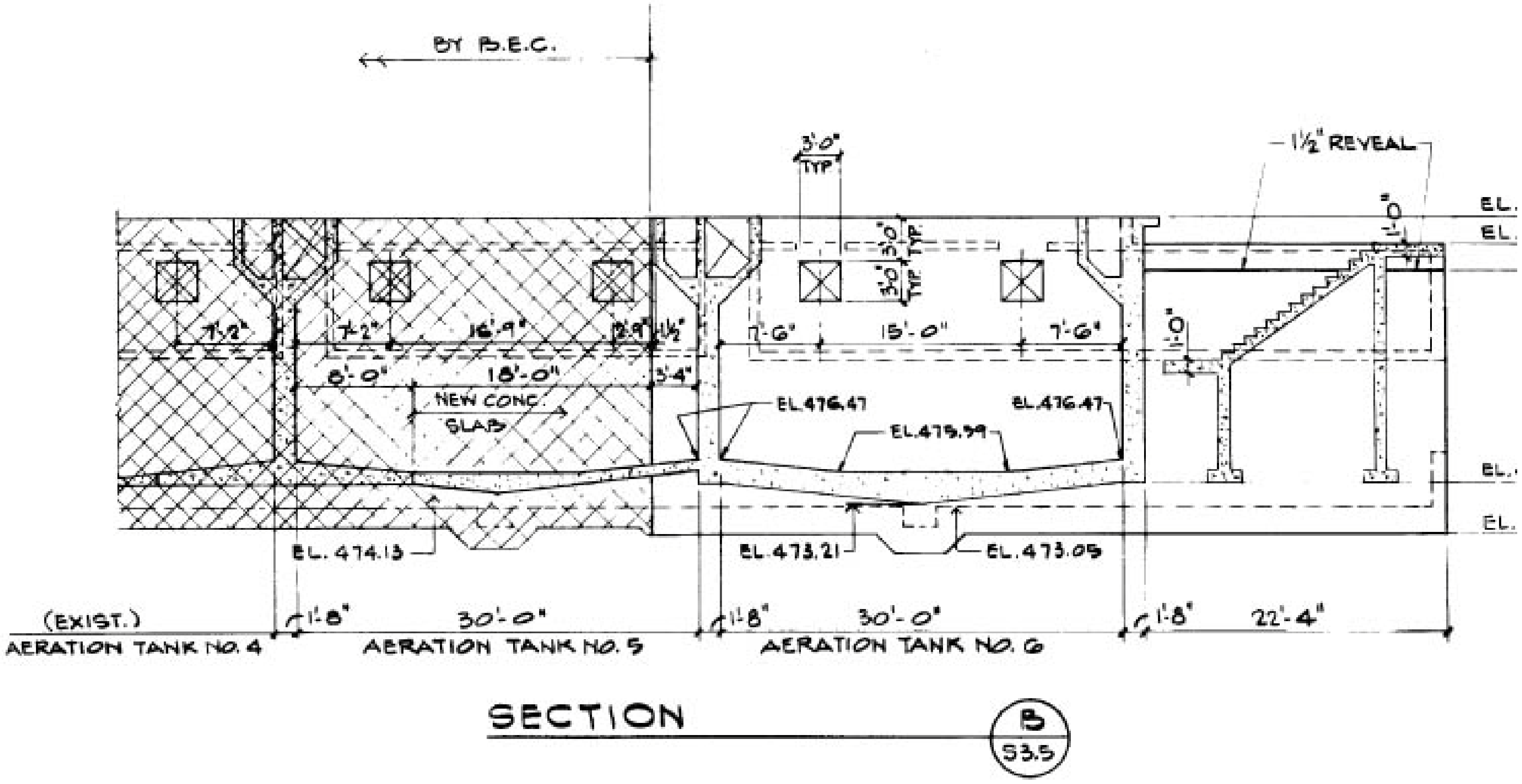


Figure D2. Drawings of the aeration tank bottom, excerpted from Kalex Engineers design drawings, dated 8-7-1987. Not to scale. See original drawings for more information. Center of tank bottom is 475.59 and wall is 476.47. The difference is 0.88 ft, well within the range of adjustment for fine pore diffuser supports. Provisions should be made to empty the tank quickly to facilitate cleaning.

Appendix B

AERATION BASIN DIFFUSER SYSTEM IMPROVEMENTS – COST ESTIMATING DATA

Engineers...Working Wonders With Water®

PROJECT SUMMARY

Estimate Class:

Project: Tapia WRF Process Air Evaluation
Client: Las Vigenes Municipal Water District
Location: Calabasas, CA.
Zip Code: 91302
Carollo Job # 8578B.00

PIC:
PM:
Date: September 19, 2011
By: Don DeMichele
Reviewed:

NO.	DESCRIPTION		TOTAL
01	Aeration Basin Upgrades		$769,261
			$0
			$0
			$0
			$0
			$0
			$0
			$0
			$0
	TOTAL DIRECT COST		**$769,261**
	Contingency	20.0%	$153,852
	Subtotal		**$923,113**
	General Contractor Overhead, Profit & Risk	12.0%	$110,774
	Subtotal		**$1,033,886**
	Escalation to Mid-Point	1.0%	$10,339
	Subtotal		**$1,044,225**
	Sales Tax (Based on)	9.8%	$102,334
	Subtotal		**$1,146,559**
	Bid Market Allowance	0.0%	$0
	TOTAL ESTIMATED CONSTRUCTION COST		**$1,146,559**
	Engineering, Legal & Administration Fees	15.0%	$171,984
	Owner's Reserve for Change Orders	5.0%	$57,328
	TOTAL ESTIMATED PROJECT COST		**$1,375,871**

The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Carollo Engineers have no control over variances in the cost of labor, materials, equipment; nor services provided by others, contractor's means and methods of executing the work or of determining prices, competitive bidding or market conditions, practices or bidding strategies. Carollo Engineers cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented as shown.

DETAILED COST ESTIMATE

Project: **Tapia WRF Process Air Evaluation**
Client: **Las Vigenes Municipal Water District**
Location: **Calabasas, CA.**
Element: **01 Aeration Basin Upgrades**

Date : **September 19, 2011**
By : **Don DeMichele**
Reviewed: **0**

SPEC. NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	SUBTOTAL	TOTAL
	Division 02 - Site Construction					
02220	Demo Steel Pipe From Trench, 18" Incl. Fittings	640	LF	$30.34	$19,419	
02220	Demo Steel Pipe From Trench, 6" Incl. Fittings	450	LF	$9.03	$4,064	
02220	Remove Valves From A Trench, 18"	4	EA	$138.42	$554	
	Total					**$24,037**
	Division 11 - Equipment					
11000	Diffuser System Replacement	1	EA	$441,180.01	$441,180	
	Total					**$441,180**
	Division 15 - Mechanical					
15000	14" Sch. 10 Type 304 Stainless Steel Pipe	80	LF	$266.40	$21,312	
15000	12" Sch. 10 Type 304 Stainless Pipe	80	LF	$219.09	$17,527	
15000	10" Sch. 10 Type 304 Stainless Steel Pipe	80	LF	$178.83	$14,307	
15000	8" Sch. 10 Type 304 Stainless Steel Pipe	240	LF	$130.28	$31,268	
15000	6" Sch. 10 Type 304 Stainless Steel Pipe	180	LF	$84.45	$15,201	
15000	14" Type 304 Stainless Welded Reducing Tee	2	EA	$6,007.23	$12,014	
15000	12" Type 304 Stainless Welded Reducing Tee	2	EA	$4,882.73	$9,765	
15000	10" Type 304 Stainless Welded Reducing Tee	4	EA	$3,767.47	$15,070	
15000	8" Type 304 Stainless Welded Tee	6	EA	$2,018.14	$12,109	
15000	6" Type 304 Stainless Welded Tee	4	EA	$1,053.96	$4,216	
15000	6" Type 304 Stainless Welded 90 Elbow	36	EA	$503.30	$18,119	
15000	14x12 Type-304 Stainless Concentric Reducer	2	EA	$1,886.30	$3,773	
15000	12x10 Type-304 Stainless Concentric Reducer	2	EA	$1,553.88	$3,108	
15000	10x8 Type-304 Stainless Concentric Reducer	4	EA	$1,252.75	$5,011	
15000	10x8 Type-304 Stainless Concentric Reducer	1	EA	$1,115.21	$1,115	
15000	8x6 Type-304 Stainless Concentric Reducer	2	EA	$871.69	$1,743	
15000	6" Type-304 Stainless Welded 45 Elbow	32	EA	$478.68	$15,318	
15000	1" NPT Thread O-Let	4	EA	$140.56	$562	
15000	14x10 Type 304 Stainless Concentric Reducer	4	EA	$2,345.44	$9,382	
15000	6" Type 304 Stainless Weld Neck Flanges 150#	64	EA	$341.35	$21,846	
15000	10" Type 304 Stainless Weld Neck Flanges 150#	2	EA	$770.78	$1,542	
15000	14" Type 304 Stainless Weld Neck Flanges 150#	2	EA	$1,371.92	$2,744	
15000	16" Carbon Steel Weld Neck Flange 150#	4	EA	$1,006.30	$4,025	
15112	6" 150# Flanged Cs Bfy Valve, No Op	16	EA	$1,495.44	$23,927	
15112	10" Vic Bfy Valve, Ci Body, Ss Bearing, Viton Disc, Gear Actuator	2	EA	$3,078.96	$6,158	
15112	6" Vic Bfy Valve, Ci Body, Ss Bearing, Viton Disc, Gear Actuator	2	EA	$1,434.68	$2,869	
15252	16" X 10" 3/8" (Std) Wall A-234 Buttwld Con Rdcr	2	EA	$2,737.10	$5,474	
15252	16" X 14" 3/8" (Std) Wall A-234 Buttwld Con Rdcr	2	EA	$2,937.66	$5,875	
	Total					**$285,381**
	Division 16 - Electrical					
16000	120 VAC Power to Thermal Flow Meter	4	EA	$2,565.00	$10,260	
	Total					**$10,260**
	Division 17 - Instrumentation and Controls					
17000	14" Thermal Mass Flow Meter	2	EA	$2,113.56	$4,227	
17000	10" Thermal Mass Flow Meter	2	EA	$2,087.91	$4,176	
	Total					**$8,403**
	Grand Total					**$769,261**

Appendix C

CONVENTIONAL SPIRAL-ROLL CHANNEL MIXING – COARSE BUBBLE DIFFUSERS

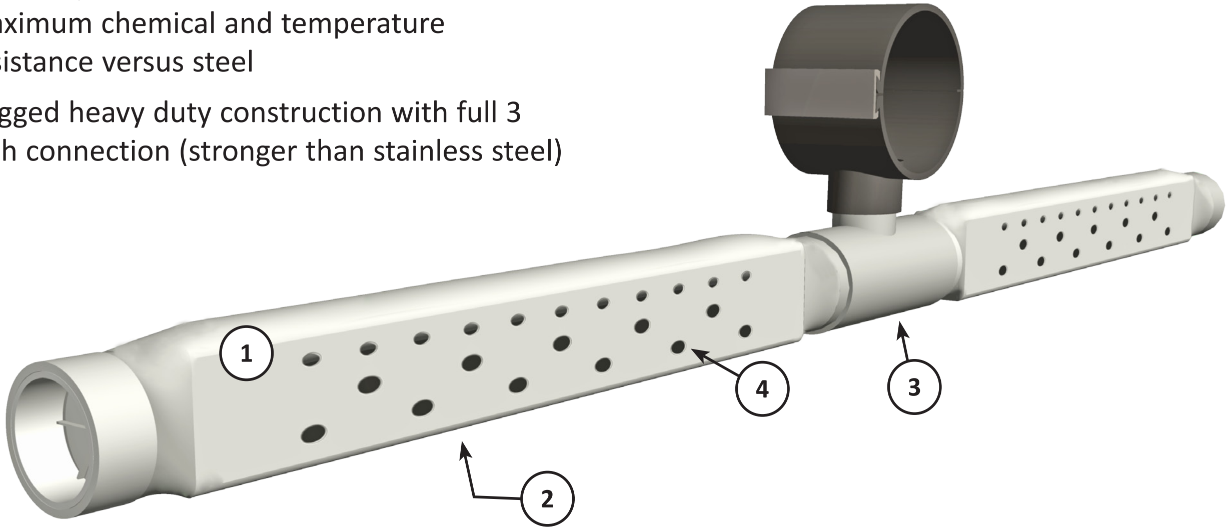
PRODUCT SPECIFICATION SHEET

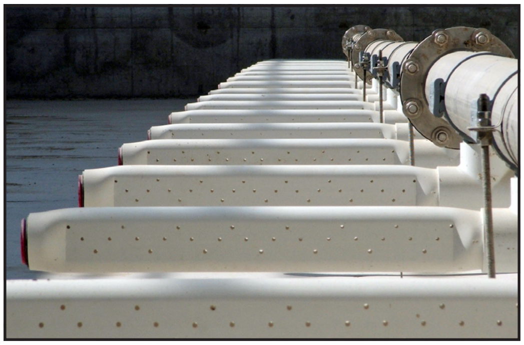
EDI MaxAir™ PVC Diffuser

with Spectrum™ Saddle Mount

MaxAir coarse bubble diffuser offers proven design and is ideal for both mixing and aeration applications

- Inverted air chamber design for uniform air release over a wide airflow range
- Full 48 inch air release perimeter
- High airflow capacity
- Available in 24 inch length
- Clog resistant self-purge design
- Standard open bottom and optional deflector bottom designs available
- PVC or optional CPVC construction for maximum chemical and temperature resistance versus steel
- Rugged heavy duty construction with full 3 inch connection (stronger than stainless steel)
- Patented Spectrum™ diffuser mount for maximum strength and ease of installation on any pipe material
- Spectrum diffuser mount available for 3 to 8 inch pipe (110 mm & 160 mm also available)
- Simplex or duplex configuration
- Standard sizes IN STOCK for immediate shipment





1. Diffuser Body
2. Standard Open Bottom
3. Full 3 inch Diameter Mount
4. Multi-Level Air Metering Orifices

www.wastewater.com

Environmental Dynamics Incorporated

Value Solutions Since 1975

PRODUCT SPECIFICATION SHEET

EDI MaxAir™ diffuser provides broad band, coarse bubble aeration for maximum mixing efficiency. The unit is available in 24 inch standard length. The 24 inch diffuser unit provides a full 48 inch air release perimeter. Air release uniformity and mixing efficiency features multi-level air metering orifice design. This provides full utilization over the entire operating range of the unit.

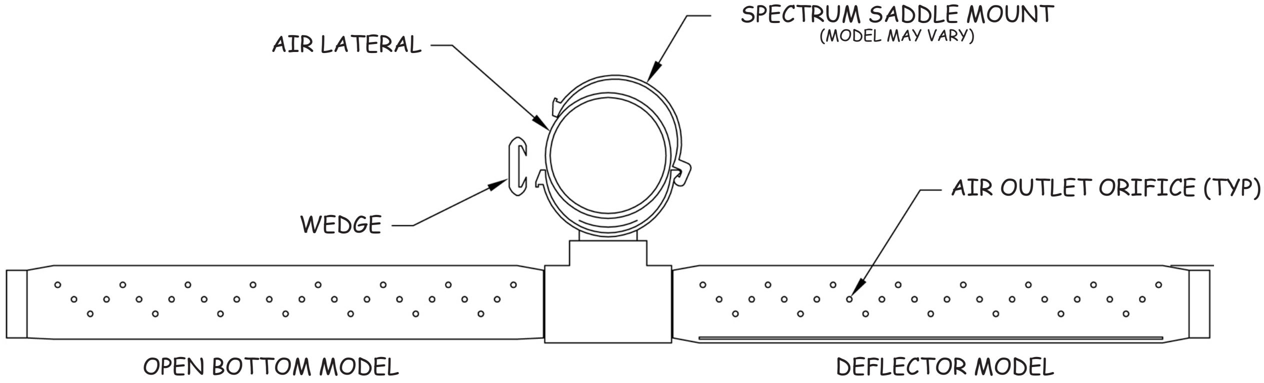
MaxAir diffusers are ideal for the most demanding aeration and mixing applications including flow equalization, channel aeration, aerobic digesters, industrial, and mixing and scouring applications including RBC, MBR, IFAS, and MBBR.

Air distribution is achieved with fixed orifices positioned on three levels. As the air flow to the diffuser increases, the number of active orifices increases thereby minimizing the pressure required for increased airflow.

The standard unit features an open bottom The diffuser may be operated under a wide range of applications including intermittent applications. Optional deflector bottom design provides a mechanism to preclude entry of large particles into the diffuser and piping components.

The MaxAir diffuser is designed for long service life. All components are PVC or optional high temperature CVPC. Diffuser body attaches to air piping using a Spectrum Diffuser Mount with full 3-inch connection.

MaxAir diffusers feature the patented Spectrum™ Diffuser Mount. This unique mounting system clamps to the outside surface of the air supply pipe and may be installed on any pipe material. Saddle mounts are available from 3 inch through 8 inch pipe sizes, plus 110 mm and 160 mm metric sizes.



Diffuser Type	Design Airflow		Diffuser Length		Orifice Size		Dry Weight		Net Operating Buoyancy	
	scfm	m^3_N/h	in	mm	ft^2	m^2	lb	kg	lb	kg
Simplex	0-50	0-48	34.0	864	Orifice engineered appropriately for each project.		6.0	2.7	11	4.9
Duplex	0-100	0-87	64.0	1630			11	5.0	17	7.7

- Optimum oxygen transfer efficiency is achieved when operating in the middle to low end of the airflow range. The approximate operating pressure of the diffuser at the mid-range is 2-4 inches (0.5-1.0 kPa).

Environmental Dynamics Inc.
5601 Paris Road • Columbia, MO 65202 USA
+1 877.EDI.AIR8 (334.2478) +1 573.474.9456

For Parts Information:
parts@wastewater.com
www.diffuserexpress.com

For System Information:
systems@wastewater.com
www.wastewater.com

Appendix D

CHANNEL MIXING SYSTEM REPLACEMENT – COST ESTIMATING DATA

Engineers...Working Wonders With Water®

PROJECT SUMMARY

Estimate Class:
PIC:
PM:
Date: May 24, 2011
By: Don DeMichele
Reviewed:

Project: **Tapia WRF-Conventional Channel Mixing System**
Client: **Las Virgenes Municipal Water District**
Location: **Calabasas, CA.**
Zip Code: **91302**
Carollo Job # **8578B.00**

NO.	DESCRIPTION		TOTAL
01	Channel Main Piping		$48,956
02	Diffuser Manufacturer Scope		$206,739
			$0
			$0
			$0
			$0
			$0
			$0
			$0
	TOTAL DIRECT COST		**$255,695**
	Contingency	5.0%	$12,785
	Subtotal		**$268,479**
	General Contractor Overhead, Profit & Risk	12.0%	$32,218
	Subtotal		**$300,697**
	Escalation to Mid-Point	1.0%	$3,007
	Subtotal		**$303,704**
	Sales Tax (Based on Gross Reciepts)	9.8%	$29,763
	Subtotal		**$333,467**
	Bid Market Allowance	0.0%	$0
	TOTAL ESTIMATED CONSTRUCTION COST		**$333,467**
	Engineering, Legal & Administration Fees	15.0%	$50,020
	Owner's Reserve for Change Orders	5.0%	$16,673
	TOTAL ESTIMATED PROJECT COST		**$400,160**

The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Carollo Engineers have no control over variances in the cost of labor, materials, equipment; nor services provided by others, contractor's means and methods of executing the work or of determining prices, competitive bidding or market conditions, practices or bidding strategies. Carollo Engineers cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented as shown.

Engineers...Working Wonders With Water®

PROJECT SUMMARY

Project:	**Tapia WRF - EnviroMix Channel Mixing System**	**Estimate Class:**	
Client:	**Las Virgenes Municipal Water District**	**PIC:**	
Location:	**Calabasas, CA.**	**PM:**	
Zip Code:	**91302**	**Date:**	**June 2, 2011**
Carollo Job #	**8578B.00**	**By:**	**Don DeMichele**
		Reviewed:	

NO.	DESCRIPTION		TOTAL
01	ChannelMix High Pressure Pip		$83,663
02	ChannelMix Electrical		$51,816
03	EnviroMix Scope		$274,186
			$0
			$0
			$0
			$0
			$0
	TOTAL DIRECT COST		**$409,665**
	Contingency	20.0%	$81,933
	Subtotal		**$491,598**
	General Contractor Overhead, Profit & Risk	12.0%	$58,992
	Subtotal		**$550,590**
	Escalation to Mid-Point	1.0%	$5,506
	Subtotal		**$556,096**
	Sales Tax (Based on Gross Reciepts)	9.8%	$54,219
	Subtotal		**$610,315**
	Bid Market Allowance	0.0%	$0
	TOTAL ESTIMATED CONSTRUCTION COST		**$610,315**
	Engineering, Legal & Administration Fees	15.0%	$91,547
	Owner's Reserve for Change Orders	5.0%	$30,516
	TOTAL ESTIMATED PROJECT COST		**$732,378**

The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Carollo Engineers have no control over variances in the cost of labor, materials, equipment; nor services provided by others, contractor's means and methods of executing the work or of determining prices, competitive bidding or market conditions, practices or bidding strategies. Carollo Engineers cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented as shown.

Engineers...Working Wonders With Water®

PROJECT SUMMARY

Estimate Class:

Project: **Tapia WRF - PumpedMix Channel Mixing System**
PIC:
Client: **Las Virgenes Municipal Water District**
PM:
Location: **Calabasas, CA.**
Date: **July 6, 2011**
Zip Code: **91302**
By: **Don DeMichele**
Carollo Job # **8578B.00**
Reviewed:

NO.	DESCRIPTION		TOTAL
01	PumpedMix Mechanical		$204,749
02	PumpedMix Electrical		$34,271
			$0
			$0
			$0
			$0
			$0
			$0
			$0
	TOTAL DIRECT COST		**$239,020**
	Contingency	20.0%	$47,804
	Subtotal		**$286,824**
	General Contractor Overhead, Profit & Risk	12.0%	$34,419
	Subtotal		**$321,243**
	Escalation to Mid-Point	1.0%	$3,212
	Subtotal		**$324,455**
	Sales Tax (Based on)	9.8%	$31,797
	Subtotal		**$356,252**
	Bid Market Allowance	0.0%	$0
	TOTAL ESTIMATED CONSTRUCTION COST		**$356,252**
	Engineering, Legal & Administration Fees	15.0%	$53,438
	Owner's Reserve for Change Orders	5.0%	$17,813
	TOTAL ESTIMATED PROJECT COST		**$427,502**

The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures. Carollo Engineers have no control over variances in the cost of labor, materials, equipment; nor services provided by others, contractor's means and methods of executing the work or of determining prices, competitive bidding or market conditions, practices or bidding strategies. Carollo Engineers cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented as shown.

Appendix E

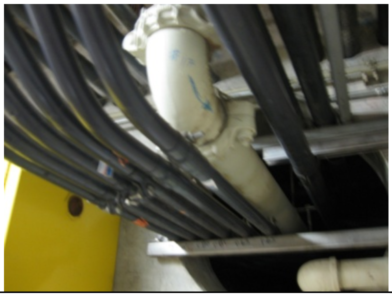
PROCESS AIR PIPING LEAK SUMMARY

<table>
<tr><td colspan="3">Leak No. 001</td></tr>
<tr><td>Description</td><td>Grooved coupling in vertical 6" pipe serving channel air near Aeration Basin No. 1.</td><td rowspan="5"></td></tr>
<tr><td>Estimated Leakage (SCFM)</td><td>2.00</td></tr>
<tr><td>Annual Energy Costs ($/Yr.)</td><td>$54.15</td></tr>
<tr><td>Estimated Repair Costs ($)</td><td>$94.15</td></tr>
<tr><td>Simple Payback Period (Yr.)</td><td>1.74</td></tr>
<tr><td colspan="3">Notes:
Repair costs based on replacing one 6” grooved coupling.</td></tr>
</table>

<table>
<tr><td colspan="3">Leak No. 011</td></tr>
<tr><td>Description</td><td>Pin hole in 3/8” tubing to orifice plate flow meter serving RAS reaeration basin No. 2.</td><td rowspan="5"></td></tr>
<tr><td>Estimated Leakage (SCFM)</td><td>8.3</td></tr>
<tr><td>Annual Energy Costs ($/Yr.)</td><td>$224.74</td></tr>
<tr><td>Estimated Repair Costs ($)</td><td>$62.04 to $113.97</td></tr>
<tr><td>Simple Payback Period (Yr.)</td><td>0.28 to 0.51</td></tr>
<tr><td colspan="3">Notes:
Repair costs based on (best case) replacement on segment on 3/8” SST tubing and (worst case) two compression unions and tubing.</td></tr>
</table>

<table>
<tr><td colspan="3">Leak No. 016</td></tr>
<tr><td>Description</td><td>Grooved tee in 6” piping at mixed liquor channel. 3” piping serves Aeration Basin No. 1 influent channel.</td><td rowspan="5"></td></tr>
<tr><td>Estimated Leakage (SCFM)</td><td>0.9</td></tr>
<tr><td>Annual Energy Costs ($/Yr.)</td><td>$23.02</td></tr>
<tr><td>Estimated Repair Costs ($)</td><td>$40.25</td></tr>
<tr><td>Simple Payback Period (Yr.)</td><td>1.75</td></tr>
<tr><td colspan="3">Notes:
Repair costs based replacement of 3” grooved coupling.</td></tr>
</table>

Leak No. 017

Description	3” grooved coupling outside Hoffman blower room.	
Estimated Leakage (SCFM)	2.0	
Annual Energy Costs ($/Yr.)	$53.34	
Estimated Repair Costs ($)	$40.25 to $413.80	
Simple Payback Period (Yr.)	0.75 to 7.76	

Notes:
Best case repair costs based on replacement of one 3” grooved coupling.
Worst case repair costs based on replacement of two (2) 3” grooved couplings, 10’-0” of grooved 3” diameter steel pipe, and one 3” grooved elbow.

Leak No. 022

Description	3” grooved coupling in RAS channel north of final sedimentation basin No. 2.	
Estimated Leakage (SCFM)	2.0	
Annual Energy Costs ($/Yr.)	$36.55	
Estimated Repair Costs ($)	$40.25 to $353.45	
Simple Payback Period (Yr.)	1.10 to 9.67	

Notes:
Best case repair costs based on replacement of one 3” grooved coupling.
Worst case repair costs based on replacement of three 3” grooved couplings and 12’-0” of grooved 3” diameter steel pipe.

Leak No. 023

Description	Grooved coupling on 6 x 3 tee in mixed liquor channel near Aeration Basin No. 2.	
Estimated Leakage (SCFM)	3.6	
Annual Energy Costs ($/Yr.)	$96.94	
Estimated Repair Costs ($)	$40.25 to $643.80	
Simple Payback Period (Yr.)	0.42 to 6.64	

Notes:
Best case repair costs based on replacement of one 3” grooved coupling.
Worst case repair costs based on replacement of one 3” grooved coupling, one 6 x 3 grooved tee, 1’-0” of grooved 3” diameter pipe, and two (2) 6” grooved couplings.

Leak No. 024

Description	Threaded ½” plug in 6” mixed liquor channel air pipe.	No photo available.
Estimated Leakage (SCFM)	2.0	
Annual Energy Costs ($/Yr.)	$53.34	
Estimated Repair Costs ($)	$6.72	
Simple Payback Period (Yr.)	0.13	

Notes:
Repair costs based on replacement of one ½” threaded plug..

Leak No. 025

Description	Gasket of 36” check valve in vault near RAS reaeration basins.	
Estimated Leakage (SCFM)	16.0	
Annual Energy Costs ($/Yr.)	$433.24	
Estimated Repair Costs ($)	$1,190	
Simple Payback Period (Yr.)	2.75	

Notes:
Repair costs based on replacement of two 36” gaskets and rental of portable crane hoist.
Worst case repair costs based on replacement of two 36” gaskets, 36” check valve, and rental of portable crane hoist.

Leak No. 026 & 027

Description	Grooved 3” cap and coupling in primary sedimentation basin feed channel near basin No. 1.	
Estimated Leakage (SCFM)	6.0	
Annual Energy Costs ($/Yr.)	$162.46	
Estimated Repair Costs ($)	$40.25 to $130.65	
Simple Payback Period (Yr.)	0.25 to 0.80	

Notes:
Best case repair costs based on replacement of one 3” grooved coupling.
Worst case repair costs based on replacement of one 3” grooved coupling and one 3” grooved cap.

Leak No. 028

Description	2” mixing air drop leg in primary sedimentation basin feed channel near basin No. 3.	No photo available.
Estimated Leakage (SCFM)	72.0	
Annual Energy Costs ($/Yr.)	$1,946.56	
Estimated Repair Costs ($)	$67.45 to $423.15	
Simple Payback Period (Yr.)	0.03 to 0.22	

Notes:
Best case repair costs based on capping 2” drop leg.
Worst case repair costs based on replacement of 10’-0” of 2” threaded steel piping and one (1) 2” angle globe valve.

Leak No. 029

Description	2” mixing air drop leg in primary sedimentation basin feed channel near basin No. 3.	
Estimated Leakage (SCFM)	3.5	
Annual Energy Costs ($/Yr.)	$94.77	
Estimated Repair Costs ($)	$67.45 to $423.15	
Simple Payback Period (Yr.)	0.71 to 4.47	

Notes:
Best case repair costs based on capping 2” drop leg.
Worst case repair costs based on replacement of 10’-0” of 2” threaded steel piping and one (1) 2” angle globe valve.

Leak No. 030

Description	Broken 2” mixing air drop leg in primary sedimentation basin feed channel – west end.	- Temporarily repaired - 
Estimated Leakage (SCFM)	328	
Annual Energy Costs ($/Yr.)	$8,881.34	
Estimated Repair Costs ($)	$67.45 to $423.15	
Simple Payback Period (Yr.)	0.01 to 0.05	

Notes:
Best case repair costs based on capping 2” drop leg.
Worst case repair costs based on replacement of 10’-0” of 2” threaded steel piping and one (1) 2” angle globe valve.

Leak No. 031

Description	Grooved 4” coupling in aeration basin feed channel south of basin No. 6.	
Estimated Leakage (SCFM)	20	
Annual Energy Costs ($/Yr.)	$541.54	
Estimated Repair Costs ($)	$55.70 to $531.36	
Simple Payback Period (Yr.)	0.10 to 0.98	

Notes:
Best case repair costs based on replacement of one (1) 4” grooved coupling.
Worst case repair costs based on replacement of three (3) 4” grooved couplings and 12’-0” of 4” diameter grooved pipe.

Leak No. 034

Description	Grooved 6” coupling at elbow near odor control area.	
Estimated Leakage (SCFM)	0.5	
Annual Energy Costs ($/Yr.)	$13.54	
Estimated Repair Costs ($)	$94.15	
Simple Payback Period (Yr.)	6.95	

Notes:
Repair costs based on replacement of one (1) 6” grooved coupling.

Leak No. 035

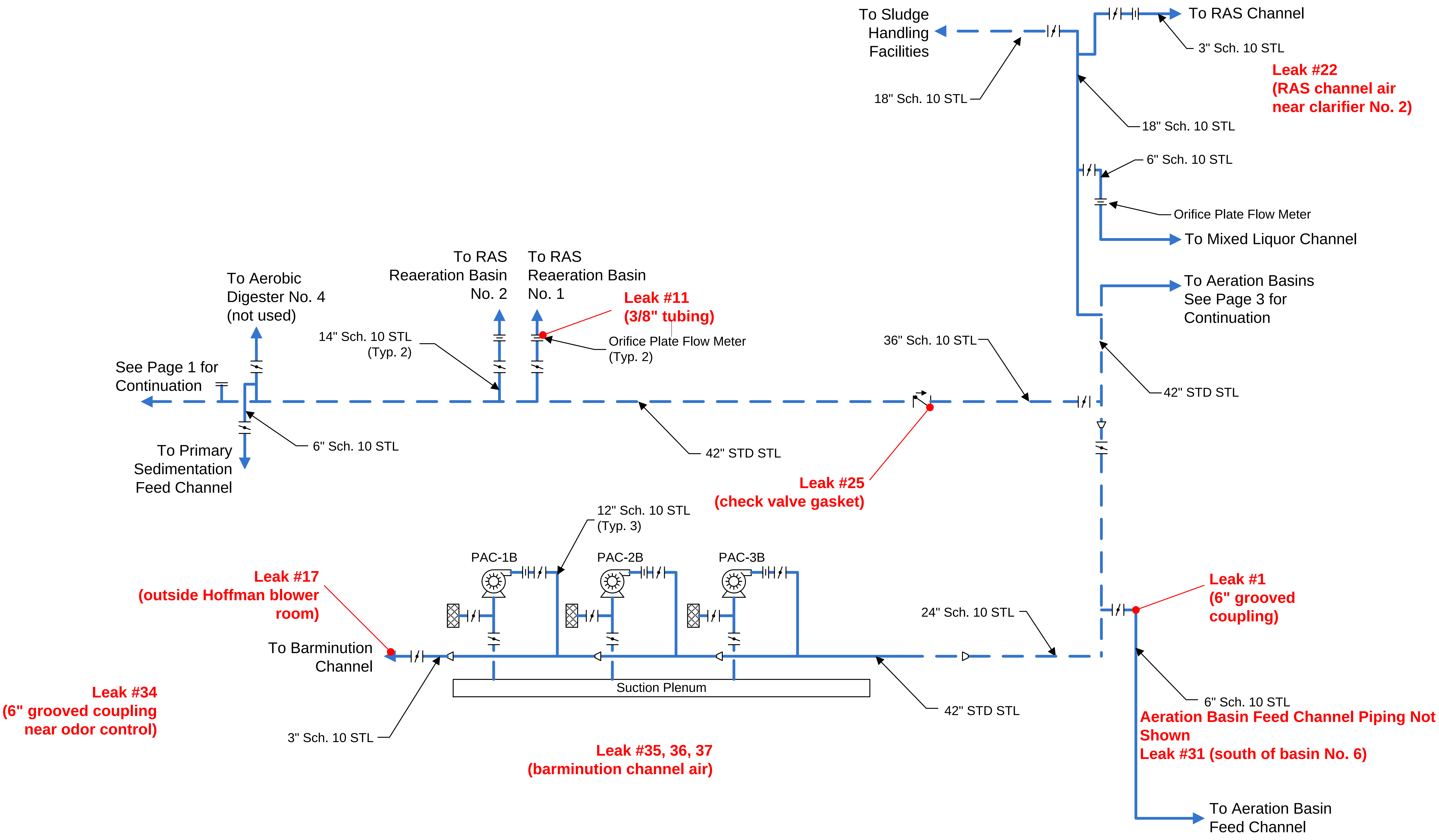
Description	Broken 1-1/4” mixing air drop leg to barminution channel – south.	
Estimated Leakage (SCFM)	20	
Annual Energy Costs ($/Yr.)	$541.54	
Estimated Repair Costs ($)	$65.25 to $485.90	
Simple Payback Period (Yr.)	0.12 to 0.90	

Notes:
Best case repair costs based on capping 1-1/4” drop leg.
Worst case repair costs based on replacement of 1-1/4” globe valve, 10’-0” of 1-1/4” diameter grooved pipe, one 1-1/4” grooved elbow, and three (3) 1-1/4” grooved couplings.

Leak No. 036		
Description	Broken 1-1/4” mixing air drop leg to barminution channel – north.	
Estimated Leakage (SCFM)	20	
Annual Energy Costs ($/Yr.)	$541.54	
Estimated Repair Costs ($)	$65.25 to $485.90	
Simple Payback Period (Yr.)	0.12 to 0.90	
Notes: Best case repair costs based on capping 1-1/4” drop leg. Worst case repair costs based on replacement of 1-1/4” globe valve, 10’-0” of 1-1/4” diameter grooved pipe, one 1-1/4” grooved elbow, and three (3) 1-1/4” grooved couplings.		

Leak No. 037		
Description	Grooved 3” coupling at roof of CP-100 room.	
Estimated Leakage (SCFM)	2.0	
Annual Energy Costs ($/Yr.)	$54.15	
Estimated Repair Costs ($)	$40.25 to 375.35	
Simple Payback Period (Yr.)	0.74 to 6.93	
Notes: Best case repair costs based on replacement of one (1) 3” grooved coupling. Worst case repair costs based on replacement of two (2) 3” grooved couplings, 0’-6” of grooved 3” diameter pipe, and one (1) 4 x 3 grooved concentric reducer.		

The total annual energy cost savings provided by repairs to leaks listed in this appendix is $13,800. Total estimated costs to repair leaks are between $2,000 and $6,000. Leak repair cost estimates include a contractor overhead and profit margin of 15 percent. Simple payback period to repair these leaks is between 0.15 and 0.43 years.



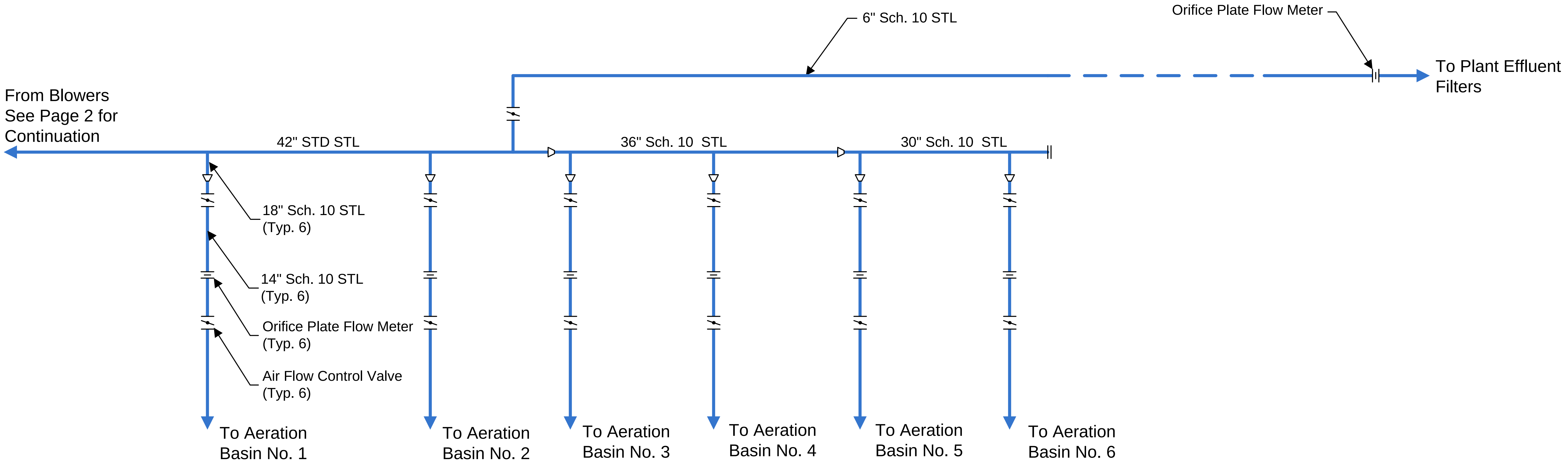
Leak #30
(west end of primary clarifier feed channel - capped)

Leak #28/29
(near primary clarifier No. 3)

Leak #26/27
(near primary clarifier No. 1)

Tapia WRF – Process Air System Schematic
Page 2 of 3

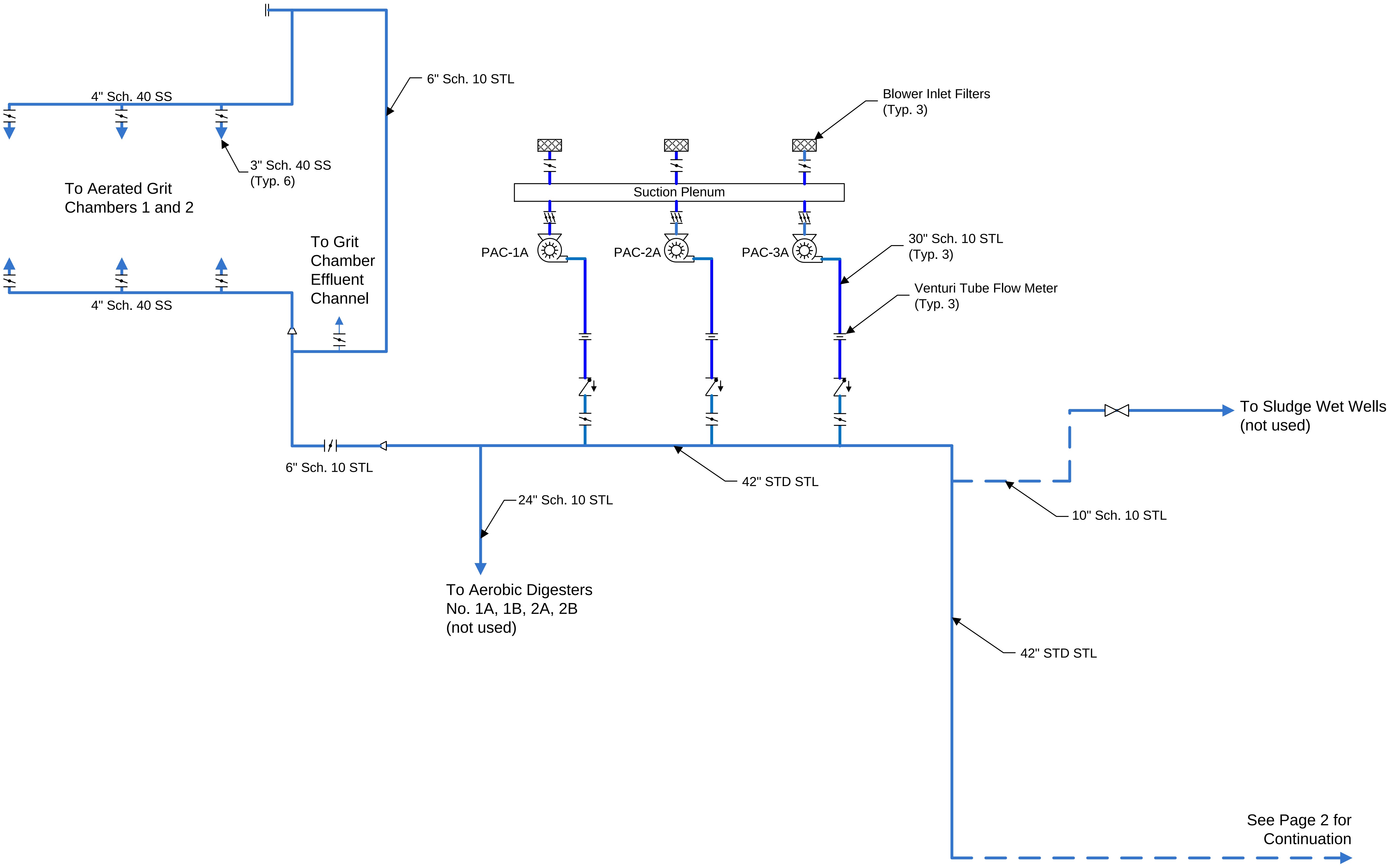
Leaks in Mixed Liquor Channel Air Piping (not shown)
#16 – Near basin No. 1
#23 – Near basin No. 2
#24 – Between basins No. 2 and 3



Tapia WRF – Process Air System Schematic
Page 3 of 3

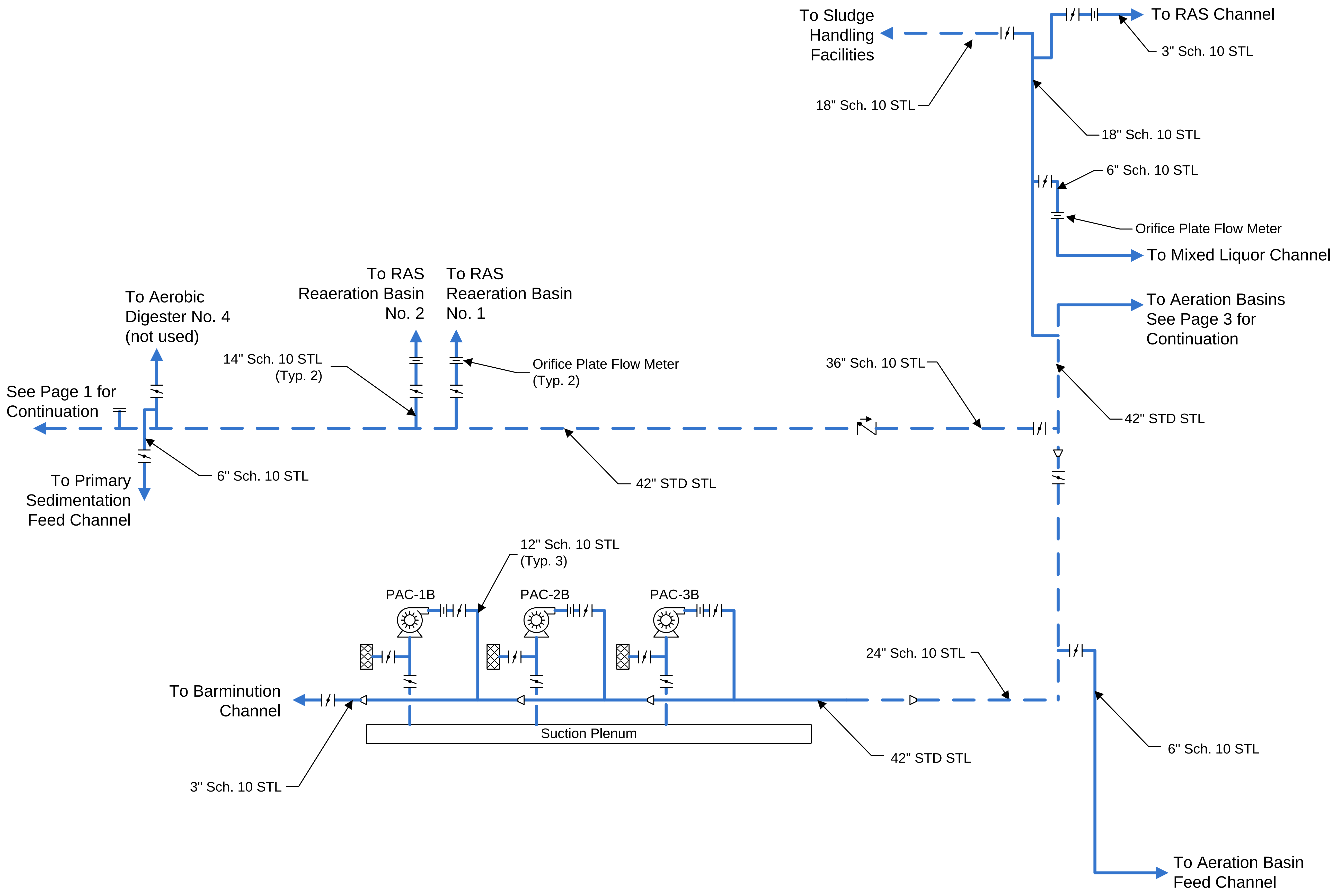
Appendix F

PROCESS AIR PIPING SCHEMATICS

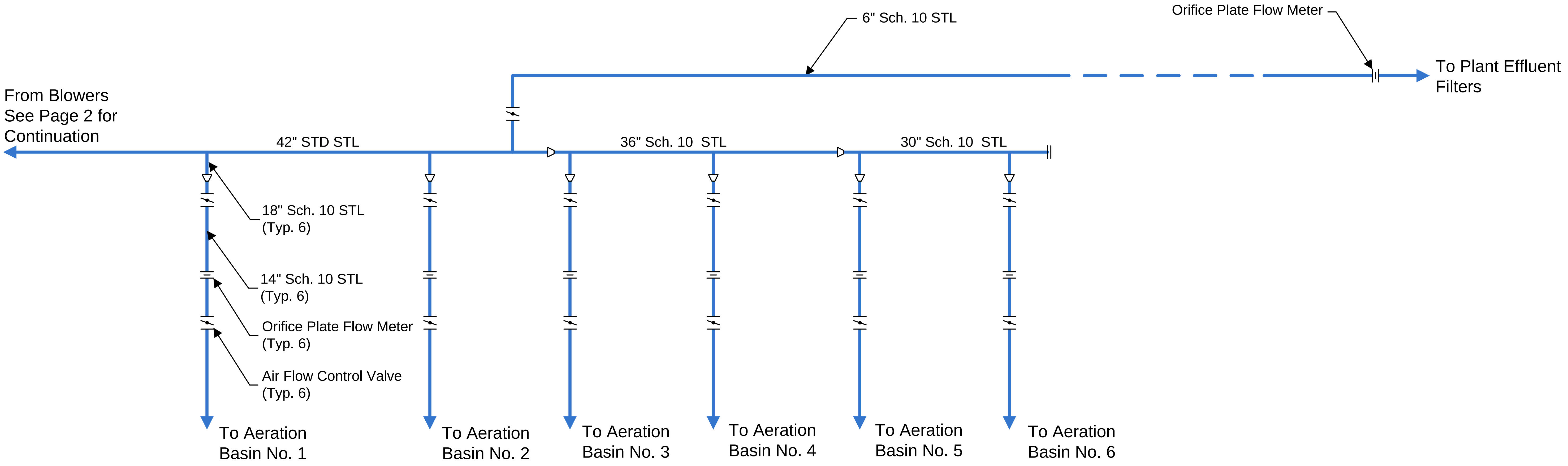


Tapia WRF – Process Air System Schematic

Page 1 of 3



Tapia WRF – Process Air System Schematic
Page 2 of 3



Tapia WRF – Process Air System Schematic

Page 3 of 3