West Basin Facility Plan Project 7054

TECHNICAL MEMORANDUM 12

Forest Grove WRRF Aeration System Evaluation

FINAL / September 2025

Produced by: carollo

Clean Water Services

Clean Water Services

West Basin Facility Plan Project 7054

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Forest Grove WRRF Aeration System Evaluation

FINAL / September 2025

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Abbreviations

α	oxygen transfer efficiency factor
AB	aeration basin
Ad	diffuser active area
AFT	Applied Flow Technology
At	tank floor area
CAMP®	Concentrated Accelerated Motivated Problem Solving
cfm	cubic foot per minute
District	Clean Water Services
DO	dissolved oxygen
DW	dry weather
EI&C	electrical, instrumentation, and control
F	diffuser fouling factor
hp	horsepower
HVAC	heating, ventilation, and air conditioning
mg/L	milligrams per liter
mgd	million gallons per day
MSC	multistage centrifugal
P	pressure
PD	positive displacement
psi	pound per square inch
psig	pound per square inch, gauge
Q/nd	air flow rate per diffuser
SCADA	supervisory control and data acquisition
scfm	standard cubic foot per minute
sf	square feet
VFD	variable frequency drive
WRRF	water resource recovery facility
WW	wet weather

TM 12 FOREST GROVE WRRF AERATION SYSTEM EVALUATION

12.1 Executive Summary

Clean Water Services (the District) has needed to operate the existing aeration system at the Forest Grove Water Resource Recovery Facility (WRRF) at its installed capacity to satisfy peak oxygen demand conditions. During the West Basin Alternatives CAMP®, the project team recommended the construction of the Council Creek pump station to redirect a portion of the flow that has traditionally been tributary to the Hillsboro WRRF to the Forest Grove WRRF.[1] The Forest Grove WRRF Capacity Evaluation[2] determined that these higher loads together with operational changes at Forest Grove and Hillsboro WRRFs will require expansion of secondary treatment at the Forest Grove WRRF within the next 10 years. This technical memorandum summarizes an evaluation of the existing aeration system capacity and an assessment of air distribution piping and blower technology alternatives to provide sufficient aeration system capacity until the secondary treatment expansion project is completed and through the end of the current planning period.

This memorandum is organized as follows:

- Sections 12.2 and 12.3 describe the drivers for the present evaluation and the major components of the existing aeration system, respectively.
- Section 12.4 summarizes the capacity evaluation of the existing system.
- Sections 12.5, 12.6, and 12.7 detail the diffuser grid improvements, air distribution piping alternatives, and blower alternatives, respectively, evaluated to deliver the projected oxygen demands.
- Section 12.8 summarizes the capital costs for the first phase of aeration system capacity expansion.
- Section 12.9 summarizes the conclusions from this analysis and recommendations for next steps.

12.2 Drivers for Evaluating the Aeration System

The present evaluation was motivated by the following factors:

- The District has found that operating secondary treatment to achieve complete nitrification year-round results in improved settling. Secondary treatment was originally designed to be operated to not nitrify, with ammonia oxidation occurring downstream in the vertical flow wetland. By shifting nitrification to secondary treatment, the oxygen demand is higher than the aeration system and subsequent upgrades were designed to satisfy.[3,4]

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[1] Carollo Engineers, Inc. (March 2023). TM 1 - West Basin Alternatives CAMP®, West Basin Facility Plan Project 7054.

[2] Carollo Engineers, Inc. (October 2024). TM 10 - Forest Grove WRRF Capacity Assessment, West Basin Facility Plan Project 7054.

[3] Black & Veatch (July 2008). Preliminary Design Report Volume 1. Forest Grove WWTF Liquid Stream Upgrade Project. CWS Project No. 6336.50.

[4] Carollo Engineers, Inc., (November 2016). Forest Grove Wastewater Treatment Facility Aeration System Evaluation.

- The Forest Grove WRRF receives significant industrial and agricultural loads each year in late summer. These high loads, coupled with the need for year-round nitrification in secondary treatment, have required that the District operate with all blowers in service for short periods to maintain aeration basin dissolved oxygen (DO) set points.
- During the West Basin Alternatives CAMP®, the project team recommended the construction of the Council Creek pump station to redirect a portion of the Forest Grove collection system flow that has traditionally been tributary to the Hillsboro WRRF to the Forest Grove WRRF.[5]
- The Forest Grove WRRF Capacity Assessment[6] found that expansion of secondary treatment will be necessary by between 2031 and 2035 (Figure 12.1):
  - The District is currently adding two 100 foot diameter primary clarifiers to the Forest Grove WRRF. While it is anticipated that the addition of primary treatment would reduce the aeration requirement in secondary treatment, the following changes to operation at Forest Grove and Hillsboro WRRFs are anticipated to increase the overall aeration requirement at the Forest Grove WRRF:
    - The Hillsboro WRRF primary clarifiers will not be operated during the summer.
    - The District plans to reduce the minimum flow rate used to carry solids from the Forest Grove WRRF to the Rock Creek WRRF to 1 million gallons per day (mgd).

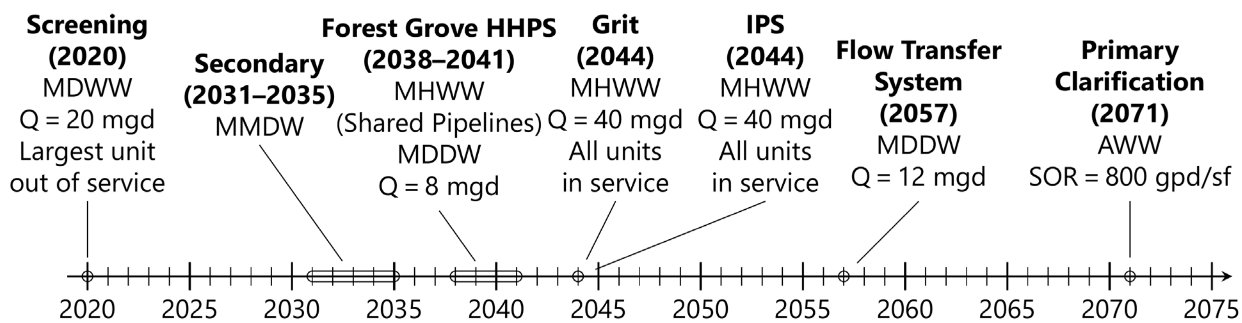

Figure 12.1 Forest Grove WRRF Trigger Year Timeline

12.3 Existing System

The existing aeration system is depicted schematically in Figure 12.2. Air from up to five blowers is delivered through low pressure air distribution piping to the aerated zones of the two aeration basins and the post-aeration channel. These elements are each detailed below.

[5] Carollo Engineers, Inc. (March 2023). TM 1 - West Basin Alternatives CAMP®, West Basin Facility Plan Project 7054.
[6] Carollo Engineers, Inc. (October 2024). TM 10 - Forest Grove WRRF Capacity Assessment, West Basin Facility Plan Project 7054.

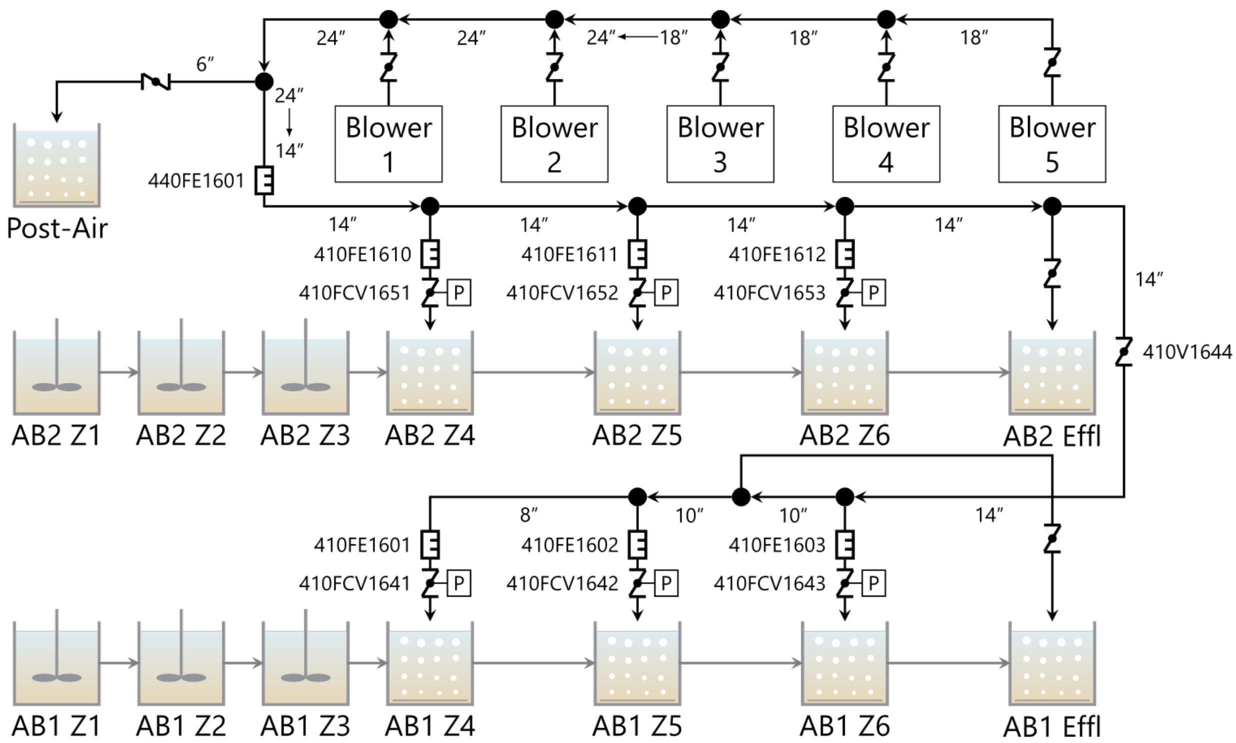

Figure 12.2 Simplified Schematic of the Existing Aeration System

The aeration system has evolved over the past thirty years with the following major updates:

- Forest Grove/Hillsboro Improvements Project (1995):
  - New aeration basins with an 18.2 foot side water depth and fine bubble diffusers were constructed in the southwest corner of the facility to replace the existing trickling filter treatment process.
  - Four Lamson multistage centrifugal blowers were installed to deliver 7500 standard cubic foot per minute (scfm) (firm capacity) through a 24 inch main.
- Liquid Stream Upgrade Project (2008):
  - New aeration basins with a 19.7 foot side water depth and fine bubble diffusers were constructed on the east side of the facility. The existing aeration basins were decommissioned.
  - The four Lamson blowers were repurposed and derated for the higher discharge pressure (approximately 7350 scfm firm capacity).
  - The existing 24 inch diameter main air distribution line was reduced to 14 inches to deliver low pressure air to the new aeration basins.
  - The diffuser density in Zone 4 of the new aeration basins was maximized to avoid surging.
- Blower Addition Project (2017):
  - Two of the original four Lamson blowers were replaced with three Aerzen rotary screw blowers to improve turndown and blower coverage.
  - Two of the original Lamson blowers were retained as back-up units.
  - The blower header was modified to accommodate the new blowers 3, 4, and 5.

12.3.1 Blowers

Five blowers are currently installed at the Forest Grove WRRF and are described in Table 12.1. The original Lamson blowers have reached the end of their useful service life. Blower 4 was rebuilt in spring 2021.

Table 12.1 Existing Blowers

Blower	Make	Model	Type	Installed (age)	Discharge Pressure (psi)	Power (hp)	Capacity (scfm)
Blower 1	Lamson	869-0-0-6-3-0-AD	Multistage Centrifugal	1995 (29 years)	9.6	250	2450
Blower 2	Lamson	869-0-0-6-3-0-AD	Multistage Centrifugal	1995 (29 years)	9.6	250	2450
Blower 3	Aerzen	D36S	Rotary Screw	2017 (7 years)	10.0	60	350–1050
Blower 4	Aerzen	D36S	Rotary Screw	2017 (7 years)	10.0	60	350–1050
Blower 5	Aerzen	D36S	Rotary Screw	2017 (7 years)	10.0	60	350–1050
Installed						680	8050
Firm(1)						430	5600

Notes:
(1) Largest blower out of service.
hp – horsepower; psi - pounds per square inch.

12.3.2 Air Distribution Piping

The existing low pressure air distribution piping is depicted schematically in Figure 12.2. The blower header section, yard piping plan, and aeration basin air distribution piping plan are shown in Figure 12.3, Figure 12.4, and Figure 12.5, respectively. The system consists of an 18 inch to 24 inch diameter header, a 14 inch diameter main line that delivers air from the blower building to the aeration basins, and 6 inch to 8 inch diameter branches that deliver air to each diffuser grid. There is also a 6 inch diameter line that delivers air from the header to the post aeration channel. The District has previously investigated and rectified air distribution piping leaks. Any remaining losses are considered negligible.

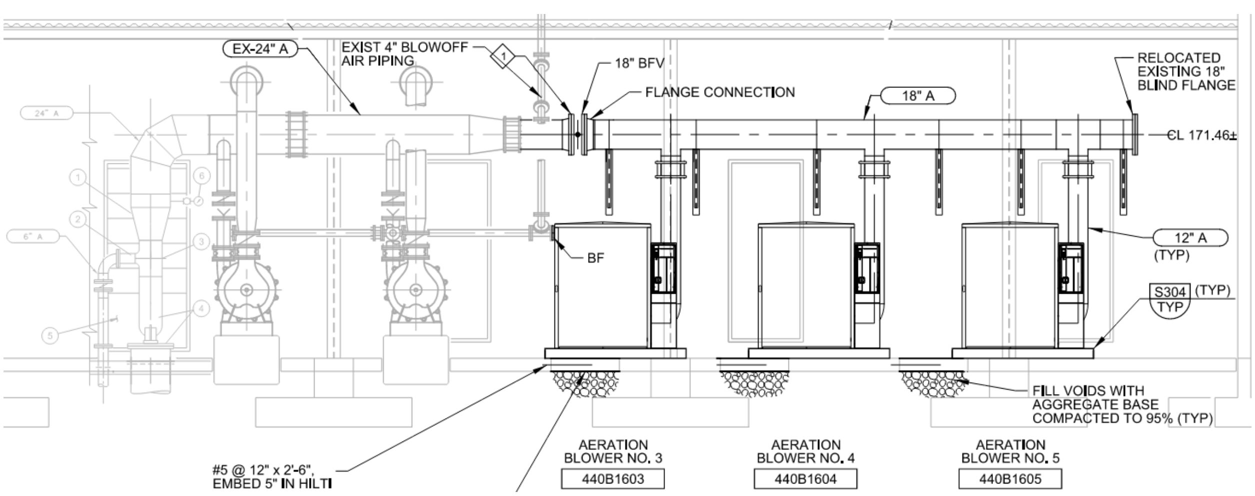

Figure 12.3 Existing Blower Header Section

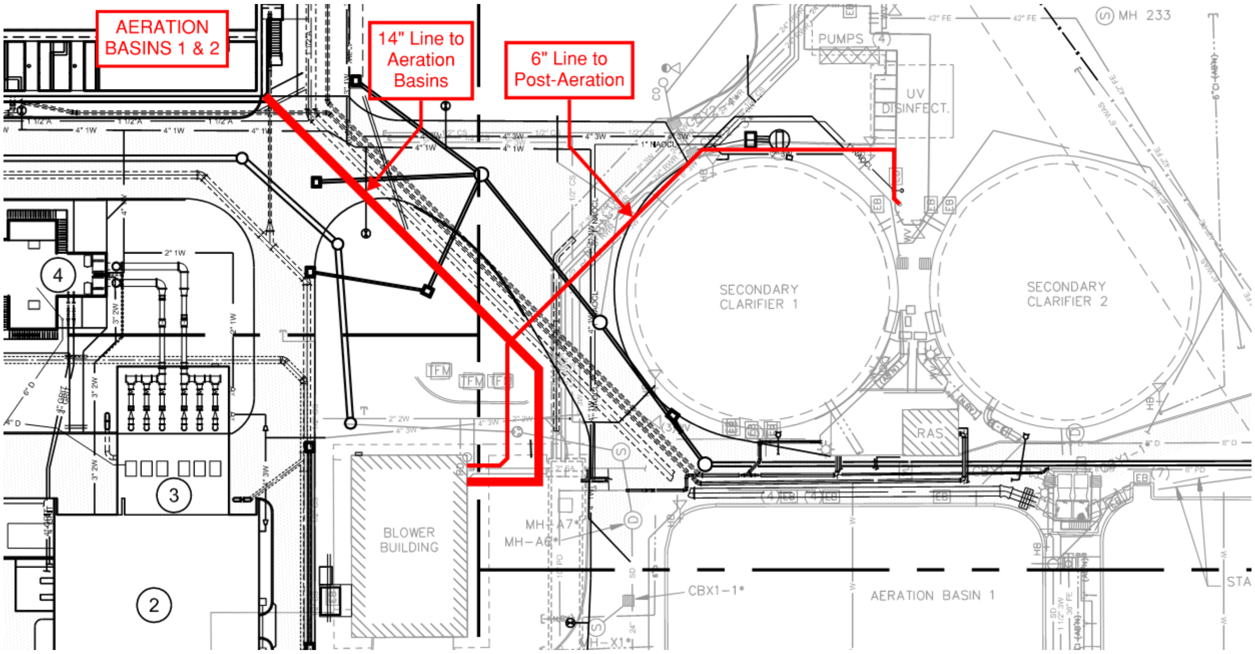

Figure 12.4 Yard Piping Plan with the Buried Air Distribution Piping Highlighted

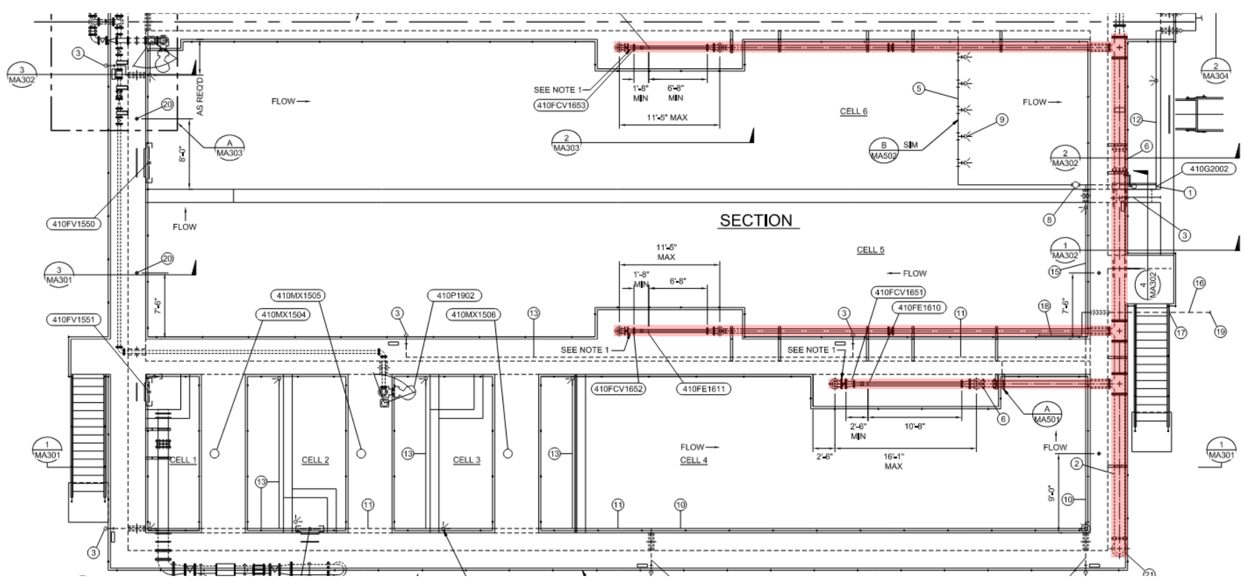

Figure 12.5 Aeration Basin 2 Upper Plan with Air Distribution Piping Highlighted

12.3.3 Aeration Basin Diffusers

Each aeration basin is outfitted with EDI 9-inch FlexAir disc diffusers with 0.25 inch flow control orifices. Diffuser counts, densities, and age for each aerated zone are summarized in Table 12.2. The air flow rate to each grid is monitored by thermal mass flow meters and controlled by flow control valves (as depicted schematically in Figure 12.2).

- The diffuser density in Zone 4 is on the upper end of feasibility. This high density was driven by the blower curve of the original Lamson blowers and the need to stay out of surge conditions. The high density has made diffuser maintenance in this zone difficult. As shown in Table 12.2, the diffusers in this zone are original (installed in 2010).
- Diffuser counts given in Table 12.2 are based on the manufacturer's submittal from the Forest Grove Liquid Stream Upgrade project[7] and discussions with the District. The District has slightly modified some of the original diffuser grids as part of pilot testing and the exact number of diffusers in each zone is not known. It was assumed that the total number of diffusers (active and blank) in the manufacturer's submittal were installed and active.
- The condition and operability of the 18 EDI 9-inch FlexAir disc diffusers in the aeration basin effluent boxes are unclear ("AB1 Effl" and "AB2 Effl" in Figure 12.2). When available, the air flow rate to these diffusers is manually controlled. It was assumed that the air flow rate to these diffusers is negligible for the present analysis.

Table 12.2 Summary of Existing Aeration Basins Diffusers

Basin/Zone	Active	Blank	Total	At/Ad(1) (sf/sf)	Density(1) (%)	Year Installed	Membrane Manufacturer	Mounting Height(2) (feet)
Aeration Basin 1								
Zone 4	676	0	676	3.7	26.9	2010	EDI FlexAir 9-in MicroPore EPDM disc	1.00 feet
Zone 5	400	0	400	11.8	8.5	2021	EDI FlexAir 9-in MicroPore EPDM disc	1.00 feet
Zone 6	380	0	380	12.4	8.1	2021	EDI FlexAir 9-in MicroPore EPDM disc	1.00 feet
Total	1456	0	1456					
Aeration Basin 2								
Zone 4	676	0	676	3.7	26.9	2010	EDI FlexAir 9-in MicroPore EPDM disc	1.00 feet
Zone 5	400	0	400	11.8	8.5	2023	EDI FlexAir 9-in MicroPore EPDM disc	1.00 feet
Zone 6	380	0	380	12.4	8.1	2023	EDI FlexAir 9-in MicroPore EPDM disc	1.00 feet
Total	1456	0	1456					

Notes:
(1) Diffuser floor coverage measured by the ratio of the floor area of the tank to the total active diffuser area (At/Ad) or the total active diffuser area divided by the tank floor area (Density).
(2) The manufacturer's submittal specified the diffuser mounting height as 1.33 feet above the floor. The mounting height was reduced to 1 foot above the floor so that the submergence assumed in the manufacturer's submittal (18.7 feet) would result in a side water depth that was consistent with the original design criteria (19.7 feet) and hydraulic profile.
Ad - diffuser active area; At - tank floor area, sf - square feet

[7] Environmental Dynamics, Inc. (2009-10-21). EDI Aeration/Mixing Equipment Installation, Operation, and Maintenance Manual - Volume 1 of 1 for Forest Grove, OR Liquid Stream Upgrade Project.

12.3.4 Post-Aeration

Air is also introduced to secondary effluent leaving Secondary Clarifiers 1 and 2 via 14 24-in wide-band coarse bubble diffusers located in the post-aeration channel (depicted in Figure 12.6). These diffusers allow the District to increase the effluent DO concentration prior to discharge to comply with their National Pollution Discharge Elimination System permit. They are typically only used during the shoulder and wet weather seasons when the Forest Grove WRRF is discharging directly to the Tualatin River, rather than through the natural treatment system. The District has used post-aeration during the summer (for example, in 2024 to keep the DO above 6 milligrams per liter [mg/L] leaving the plant).

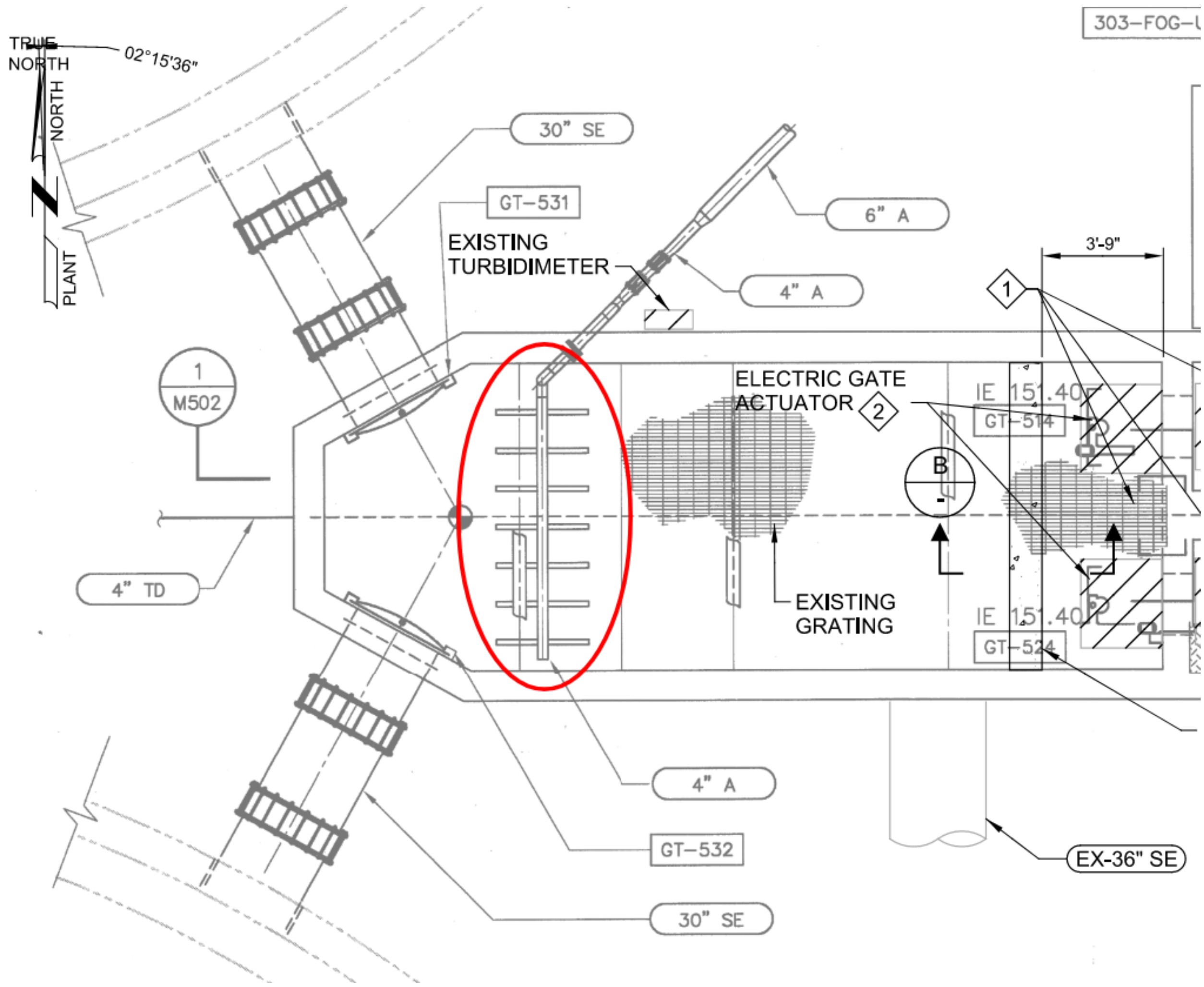

Figure 12.6 Post-Aeration Coarse Bubble Diffusers

These diffusers were originally designed to satisfy a maximum oxygen demand of 830 pounds per day with a maximum air flow rate of 640 scfm.[8] This maximum air flow rate constitutes a significant portion of the existing blower capacity (greater than 10 percent of the firm capacity). Air for these diffusers is provided from the blower header upstream of the blower header flow meter (Figure 12.2). The air flow

[8] Brown and Caldwell (1998). Forest Grove/Hillsboro Facilities Improvements. Record Drawings.

rate to these diffusers is manually controlled and is not measured. Therefore, the maximum air flow rate of 640 scfm was assumed for the present analysis. It was assumed that the diffusers are located 1 foot above the floor.

12.4 Existing Aeration System Evaluation

Air flow rate projections were developed for the existing aeration system following the approach detailed in Appendix 12A. This analysis (summarized below) found that the existing aeration system will be limited once the operational changes outlined in the Forest Grove WRRF Capacity Assessment[9] are implemented (reflected by the "Current, 2020/2024" condition).

Table 12.3 summarizes the air flow rate per diffuser for the existing diffusers. As shown:

- The projected air flow rate per diffuser will exceed the design criterion under peak conditions (values set in **bold** in Table 12.3). The diffusers in Zone 5 are limiting under each condition. The air flow rate per diffuser in Zones 4 and 6 were lower than the maximum design criteria. The air flow rate per diffuser in Zone 5:
  - Will exceed the preferred maximum design criterion of 3 scfm/diffuser under the maximum week condition once the operational changes are made and the maximum month condition by the time secondary treatment reaches capacity (2031/2035).
  - Will exceed the absolute maximum design criterion of 4 scfm/diffuser under the maximum day and peak hour conditions once the operational changes are made and the maximum week condition by the time secondary treatment reaches capacity.
  - The high air flow rate per diffuser in Zone 5 results in a high head loss across the diffusers (approximately 1.7 psi under the projected current peak hour 2031/2035 condition).
- The projected air flow rate per diffuser is less than the minimum design criteria under average wet weather and minimum day conditions (values set in *blue italic* in Table 12.3):
  - The Zone 4 diffusers limit under the average wet weather condition. Maintaining the minimum allowable air flow rate per diffuser of 0.6 scfm/diffuser in Zone 4 would require a 4 percent increase the total air flow rate from 2600 scfm to 2700 scfm under the 2020/2024 condition.
  - The wet weather minimum day condition has lower projected air flow rates, with all three zones limiting.
- Based on air flow rate per diffuser, the number of diffusers in Zone 4 could be reduced.

[9] Carollo Engineers, Inc. (October 2024). TM 10 - Forest Grove WRRF Capacity Assessment, West Basin Facility Plan Project 7054.

Table 12.3 Projected Air Flow Rate per Diffuser (scfm) with Existing Diffusers

Condition	Current (2020/2024)			Secondary Capacity (2031/2035)			End of Planning Period (2045/2049)		
	Zone 4	Zone 5	Zone 6	Zone 4	Zone 5	Zone 6	Zone 4	Zone 5	Zone 6
Minimum Day (DW)	*0.32*	0.71	*0.42*	*0.39*	0.87	*0.52*	*0.33*	0.75	*0.46*
Minimum Day (WW)	*0.21*	*0.40*	*0.33*	*0.24*	*0.46*	*0.38*	*0.19*	*0.36*	*0.30*
Average (DW)	0.74	1.64	0.97	0.89	1.99	1.20	0.76	1.71	1.06
Average (WW)	*0.49*	0.92	0.75	*0.56*	1.06	0.87	*0.43*	0.82	0.68
Maximum Month (DW)	1.35	2.92	1.82	1.63	3.58	2.24	1.38	3.01	1.93
Maximum Week (DW)	1.62	3.52	2.19	1.96	**4.31**	2.70	1.66	3.62	2.33
Maximum Day (DW)	1.90	**4.11**	2.55	2.29	**5.04**	3.15	1.94	**4.23**	2.72
Peak Hour (DW)	2.23	**4.84**	3.00	2.69	**5.93**	3.70	2.28	**4.97**	3.19

Notes:
(1) The estimated air flow rate per diffuser. Values set in *blue italic* are below the minimum recommended air flow rate per diffuser of 0.6 scfm. Values set in **bold** exceed the maximum air flow rate per diffuser (4 scfm under peak conditions).

The existing air distribution piping will also be limited under peak conditions once the aforementioned changes to operation are implemented. Figure 12.7 depicts a simplified schematic of the existing air distribution system for the 2020/2024 peak hour condition. As shown:

- The velocity in the existing air distribution piping will exceed the 4000 feet pe rminute maximum at multiple points in the system (indicted by reaches set in red in Figure 12.7). This will result in high head loss, blower discharge pressure and temperature, and potentially noise. For example, the head loss in the 14 in diameter main air distribution line from the blower room to the aeration basin will increase from 0.8 psi under the 2020/2024 peak hour condition to 1.1 psi under the 2031/2035 condition.
- The butterfly valves used to control the air flow split between the zones will need to incur head loss greater than 1.3 psi to stay within the controllable range of the valves. This will increase to 2.0 psi under the 2031/2035 peak hour condition. Larger diameter flow control tubes would be needed to reduce this head loss.

Figure 12.7 Existing Air Distribution Under the 2020/2024 Peak Hour Condition

Table 12.4 summarizes the impacts of the diffusers and air distribution system on the blowers. As shown:

- The installed capacity (all units in service) of the existing blowers will be needed to deliver the required air flow rate under the 2020/2024 maximum month and maximum week conditions (values set in *green italic* in the "ABs" and "Total" columns in Table 12.4). The existing blowers will not be able to deliver the maximum day or peak hour air flow rate for 2020/2024 (values set in **bold** in those columns). By the 2031/2035 condition, the existing blowers will not be able to deliver the air flow rate under the maximum week condition.
- As a result of the high head losses across the diffusers and air distribution piping, the blower discharge pressure will exceed the rated discharge pressure of the existing Aerzen blowers (10 psi) under 2020/2024 maximum week, maximum day, and peak hour conditions (values set in **bold** in the "P" columns in Table 12.4).

Table 12.4 Projected Air Flow Rate and Pressure for Existing Aeration System

Condition	Current (2020/2024)				Secondary Capacity (2031/2035)				End of Planning Period (2045/2049)			
	ABs[1] (scfm)	Q/nd[2] (scfm)	Total[3] (scfm)	P[4] (psi)	ABs[1] (scfm)	Q/nd[2] (scfm)	Total[3] (scfm)	P[4] (psi)	ABs[1] (scfm)	Q/nd[2] (scfm)	Total[3] (scfm)	P[4] (psi)
Minimum Day (DW)	1300	*0.3*	1300	8.6	1600	*0.4*	1600	8.6	2100	*0.3*	2100	n/a[5]
Minimum Day (WW)	860	*0.2*	1500	8.5	990	*0.2*	1600	8.5	1100	*0.2*	1800	n/a[5]
Average (DW)	3000	1.6	3000	9.0	3700	2.0	3700	9.3	4800	0.8	4800	n/a[5]
Average (WW)	2000	*0.9*	2600	8.7	2300	*1.1*	2900	8.7	2600	*0.4*	3300	n/a[5]
Maximum Month (DW)	5500	2.9	*6200*	**10.2**	*6800*	3.6	*7400*	**11.0**	**8600**	1.4	**9200**	n/a[5]
Maximum Week (DW)	*6700*	3.5	*7300*	**11.0**	**8200**	**4.3**	**8800**	**12.1**	**10,400**	1.7	**11,000**	n/a[5]
Maximum Day (DW)	*7800*	**4.1**	**8400**	**11.9**	**9500**	**5.0**	**10,200**	**13.4**	**12,100**	**1.9**	**12,700**	n/a[5]
Peak Hour (DW)	**9200**	**4.8**	**9800**	**13.1**	**11,200**	**5.9**	**11,800**	**15.1**	**14,200**	**2.3**	**14,900**	n/a[5]

Notes:

(1) The total air flow rate to the aeration basins. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).

(2) The minimum air flow rate per diffuser for minimum day (DW) and minimum day (WW) and the maximum air flow rate per diffuser otherwise. Values set in *blue italic* fall below the minimum air flow rate per diffuser or minimum air flow rate for mixing design criteria. Values set in **bold** exceed the maximum air flow rate per diffuser design criterion for the corresponding condition.

(3) The total air flow rate, equal to the sum of the total air flow rate to the aeration basins and air flow rate to the post-aeration diffusers. The air flow rate to the post-aeration diffusers was assumed to be 640 scfm. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).

(4) Estimated blower discharge pressure. Values set in *red italic* exceed the rated discharge pressure of the existing Lamson blowers (9.6 psi). Values set in **bold** exceed the rated discharge pressure of the existing Aerzen blowers (10 psi).

(5) The blower discharge pressure with the existing diffusers was not estimated for the end of planning period as the existing air distribution piping will not be sufficient for this condition.

AB - aeration basins; DW - dry weather; P - blower discharge pressure; Q/nd - air flow rate per diffuser; WW - wet weather.

As shown in Table 12.4, the process conditions corresponding to existing secondary treatment capacity (the 2031/2035 condition) result in the highest air flow rate per diffuser and blower discharge pressures under peak conditions. With the construction of a third aeration basin, the peak air flow rate per diffuser at the end of the planning period (the 2045/2049 condition) will be reduced close to the values projected immediately after the process changes are implemented.

12.5 Diffuser Grid Modifications

The existing diffuser grids in Aeration Basins 1 and 2 will need to be modified to satisfy the projected process oxygen transfer requirements. As noted above, the high air flow rates required from the existing diffusers in Zone 5 exceed the maximum air flow rate per diffuser design criterion. These high air flow rates also result in high diffuser pressure drops which contribute to a high blower discharge pressure.

In addition to the design criteria summarized in Appendix 12A, the following assumptions were made to select the diffuser grid modifications for the present analysis:

- The current 9 inch membrane disc form factor would be used. Alternative diffuser technologies that may be able to deliver higher oxygen transfer efficiencies (e.g., panels) were not considered as this would require the removal and replacement of all existing drop legs, manifolds, and laterals.
- The current membrane perforation option (EDI FlexAir MicroPore) would be used.
- The diffuser membranes in Zone 4 would be replaced in each aeration basin since they are beyond their useful life.
- If possible, diffusers would be removed from Zone 4 to improve accessibility for maintenance.
- The new aeration basin constructed as part of secondary treatment expansion would replicate the existing aeration basins and use the same diffuser technology and modified grid layouts.

Based on these assumptions, modifications to the existing diffuser grids in Zones 4 and 5 were developed to meet the projected air flow rates. These modifications are shown in Figure 12.8 and include:

- Remove eight laterals (208 diffusers) from Zone 4. This will reduce the active diffuser density from 26.8 percent to 18.9 percent and create accessways that will allow access to most of the remaining diffusers.
- Replace the remaining 468 membranes in Zone 4 with new EDI Flex Air MicroPore membranes.
- Install 160 additional active EDI FlexAir MicroPore 9 inch membrane disc diffusers into Zone 5 of each aeration basin. This would increase the active diffuser density from 8.5 percent to 11.6 percent. It was assumed that the existing diffuser grid would need to be modified to accommodate the four additional laterals to maintain even air distribution and sufficient space for diffuser maintenance. Depending on the spacing between diffusers on the laterals, the additional laterals would allow for the installation of up to 10 percent blanks.
- Replace the existing 6 inch diameter air distribution manifolds in Zones 5 and 6 with 10 inch and 8 inch diameter manifolds, respectively.

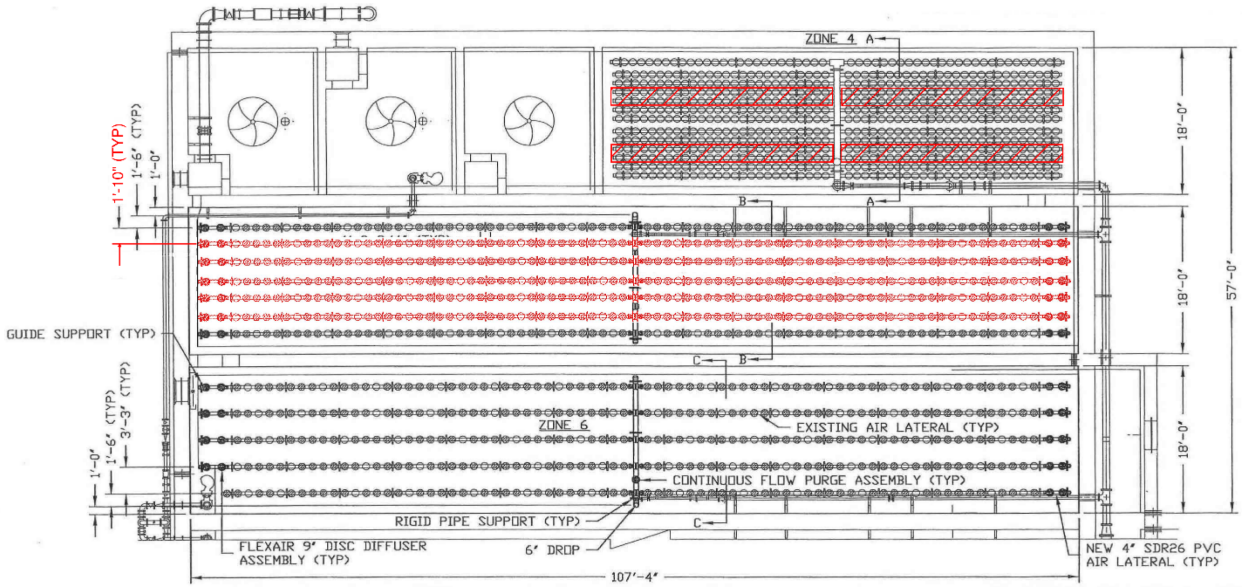

Figure 12.8 Diffuser Grid Modifications Typical of Both Aeration Basins

Table 12.5 summarizes the projected air flow rate per diffuser in each aerated zone with the diffuser grid modifications described above. As shown, the air flow rates per diffuser generally fall in the 0.6 scfm to 3 scfm range, with values above 3 scfm under some peak conditions. The air flow rate per diffuser in Zones 4 and 5 exceeds 4 scfm at the 2031/2035 condition. This was considered reasonable since:

- The peak hour condition is transient and is expected to occur infrequently.
- The condition is expected to be alleviated with the construction of a third aeration basin.
- If the air flow rate to Zones 4 and 5 is capped based on the maximum air flow rate per diffuser, only a minor DO reduction from the 2 mg/L design criterion is expected: Steady state oxygen transfer modeling indicates DO concentrations in Zones 4 and 5 of 1.7 mg/L and 1.9 mg/L, respectively.

Table 12.5 Projected Air Flow Rate per Diffuser (scfm) with Diffuser Grid Modifications

Condition	Current (2020/2024)			Secondary Capacity (2031/2035)			End of Planning Period (2045/2049)		
	Zone 4	Zone 5	Zone 6	Zone 4	Zone 5	Zone 6	Zone 4	Zone 5	Zone 6
Minimum Day (DW)	*0.49*	*0.49*	*0.42*	*0.59*	0.60	*0.52*	*0.51*	*0.51*	*0.46*
Minimum Day (WW)	*0.32*	*0.28*	*0.33*	*0.37*	*0.32*	*0.38*	*0.28*	*0.25*	*0.30*
Average (DW)	1.13	1.13	0.97	1.36	1.37	1.20	1.16	1.18	1.06
Average (WW)	0.74	0.64	0.75	0.85	0.73	0.87	0.65	*0.57*	0.68
Maximum Month (DW)	2.08	2.00	1.82	2.53	2.43	2.24	2.13	2.05	1.93
Maximum Week (DW)	2.51	2.41	2.19	3.05	2.93	2.70	2.57	2.47	2.33
Maximum Day (DW)	2.93	2.81	2.55	3.56	3.42	3.15	3.00	2.89	2.72
Peak Hour (DW)	3.45	3.30	3.00	**4.19**	**4.02**	3.70	3.52	3.39	3.19

Notes:
(1) The estimated air flow rate per diffuser. Values set in *blue italic* are below the minimum recommended air flow rate per diffuser of 0.6 scfm. Values set in **bold** exceed the maximum air flow rate per diffuser (4 scfm under peak conditions).

12.6 Air Distribution Piping Alternatives

As noted above, the existing air distribution piping will not provide sufficient capacity to deliver the required projected peak air flow to the aeration basins without exceeding the maximum recommended velocity and incurring significant head loss. Alternatives were developed based on the design criteria summarized in Appendix 12A with the following assumptions:

- The aeration system (diffusers, air distribution piping, and blowers) will be modified prior to the construction of the third aeration basin. As noted above, the capacity of each of these components will be exceeded once the operational changes are implemented at Forest Grove.
- The diffuser modifications discussed above will be completed.
- The maximum air flow rate per diffuser will be limited to 4 scfm in Zones 4 and 5. As discussed above, this occurs during the transient 2031/2035 peak hour condition with the diffuser modifications.
- Air distribution piping modifications will occur in two phases:
  - Phase 1: Modifications completed prior to the secondary capacity expansion project, accounting for the requirements of the third aeration basin, and sized for the 2045/2049 condition.
  - Phase 2: Modifications occurring with the construction of the third aeration basin needed to expand secondary treatment capacity beyond the 2031/2035 condition. This aeration basin will be located to the east of Aeration Basins 1 and 2.

Each alternative included the following modifications to the existing air distribution piping (shown schematically in Figure 12.9):

- Increase the pipe diameter for the air flow meters and flow control valves from 4 inches to 6 inches.
- Increase the lateral and drop leg diameter for Zone 4 from 8 inches to 10 inches.
- Increase the lateral and drop leg diameter for Zones 5 and 6 from 6 inches to 8 inches.
- Increase the diameter of the blower header in the blower building from 24 inches to 30 inches.

The three alternatives are described below and were developed with the following approaches:

- Alternative 1 - Replace existing as needed to meet velocity criteria for peak hour conditions.
- Alternative 2 - Leverage existing to meet velocity criteria for maximum day conditions.
- Alternative 3 - Leverage existing to meet velocity criteria in above ground piping for peak hour.

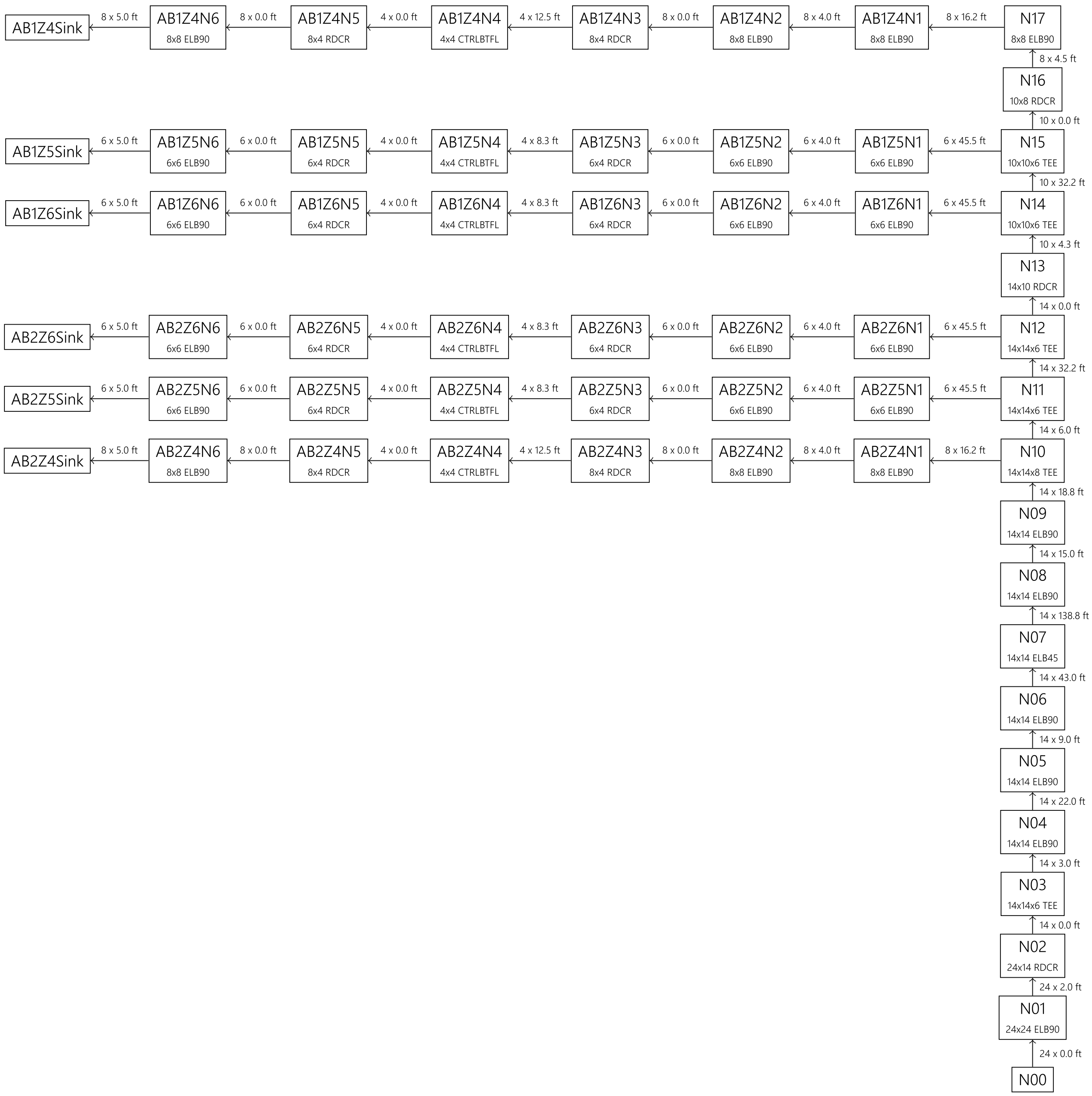

Figure 12.9 Existing Aeration System Schematic

12.6.1 Alternative 1

As noted above, the velocity under peak hour conditions will exceed the maximum threshold in many reaches of the existing air distribution piping when the operational changes are instituted. By the 2031/2035 condition, all reaches will be deficient on this basis. Alternative 1 was developed to evaluate air distribution piping replacement as needed to meet the maximum velocity criterion under the 2045/2049 peak hour condition. This requires the complete replacement of all air distribution piping, including:

- Increase the diameter of the manifold delivering air to the individual zones (as described in Alternative 3).
- Increase the diameter of the pipe from the blower building to Aeration Basin 2 from 14 inches to 30 inches.

These modifications will maintain pipe velocities below the maximum velocity criterion throughout the system.

Table 12.6 summarizes the impact of air distribution system Alternative 1 on the blower discharge pressure. With these modifications, the blower discharge pressure under peak conditions is reduced to less than 10 psi at the 2031/2035 condition.

Table 12.6 Projected Air Flow Rate and Pressure for Air Distribution Piping Alternative 1

Condition	Current (2020/2024)				Secondary Capacity (2031/2035)				End of Planning Period (2045/2049)			
	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)
Minimum Day (DW)	1700	*0.6*	1700	8.5	1700	*0.6*	1700	8.5	2500	*0.6*	2500	8.5
Minimum Day (WW)	1700	*0.6*	2300	8.5	1700	*0.6*	2300	8.5	2500	*0.6*	3200	8.5
Average (DW)	3000	1.1	3000	8.6	3700	1.4	3700	8.6	4800	1.2	4800	8.6
Average (WW)	2000	0.8	2600	8.5	2300	0.9	2900	8.5	2700	*0.7*	3300	8.5
Maximum Month (DW)	5500	2.1	*6200*	8.8	*6700*	2.5	*7400*	8.9	**8600**	2.1	**9200**	8.9
Maximum Week (DW)	*6700*	2.5	*7300*	8.9	*8100*	3.1	**8800**	9.2	**10,300**	2.6	**11,000**	9.0
Maximum Day (DW)	*7800*	2.9	**8400**	9.1	**9500**	3.6	**10,100**	9.4	**12,100**	3.0	**12,700**	9.2
Peak Hour (DW)	**9100**	3.4	**9800**	9.3	**11,000**	**4.0**	**11,600**	*9.7*	**14,200**	3.5	**14,800**	9.5

Notes:

(1) The total air flow rate to the aeration basins. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).

(2) The minimum air flow rate per diffuser for Minimum Day (DW) and Minimum Day (WW) and the maximum air flow rate per diffuser otherwise. Values set in *blue italic* fall below the minimum air flow rate per diffuser or minimum air flow rate for mixing design criteria. Values set in **bold** exceed the maximum air flow rate per diffuser design criterion for the corresponding condition.

(3) The total air flow rate, equal to the sum of the total air flow rate to the aeration basins and air flow rate to the post-aeration diffusers. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).

(4) Estimated blower discharge pressure. Values set in *red italic* exceed the rated discharge pressure of the existing Lamson blowers (9.6 psi). Values set in **bold** exceed the rated discharge pressure of the existing Aerzen blowers (10 psi).

12.6.2 Alternative 2

Alternative 2 was developed to evaluate leveraging the existing air distribution piping where possible while still meeting the maximum velocity criterion. An evaluation of the existing 14 inch diameter air pipe from the blower building to Aeration Basin 2 suggests it would be large enough to deliver the air flow required for one aeration basin under the 2045/2049 maximum day condition, but not the 2045/2049 peak hour condition. Assuming the new blowers can deliver the required air flow at the elevated discharge pressure, noise becomes the primary concern with high pipe velocities. Assuming the noise from high pipe velocities can be accommodated for the short duration of the peak hour condition, Alternative 2 was developed to leverage the existing air distribution piping where possible to meet the maximum velocity criterion under the maximum day condition. Higher velocities were allowed under the peak hour condition. The following modifications to the existing air distribution piping were included in Alternative 2 in addition to those noted above:

- Install a 24 inch pipeline parallel to the existing 14 inch main air distribution pipe from the blower header to the aeration basins (depicted in Figure 12.10). This larger line will supply air to Aeration Basin 1 and the future Aeration Basin 3 and will alleviate the high velocity and head loss under projected peak air flow rates. The existing 14 inch main will continue to serve Aeration Basin 2.

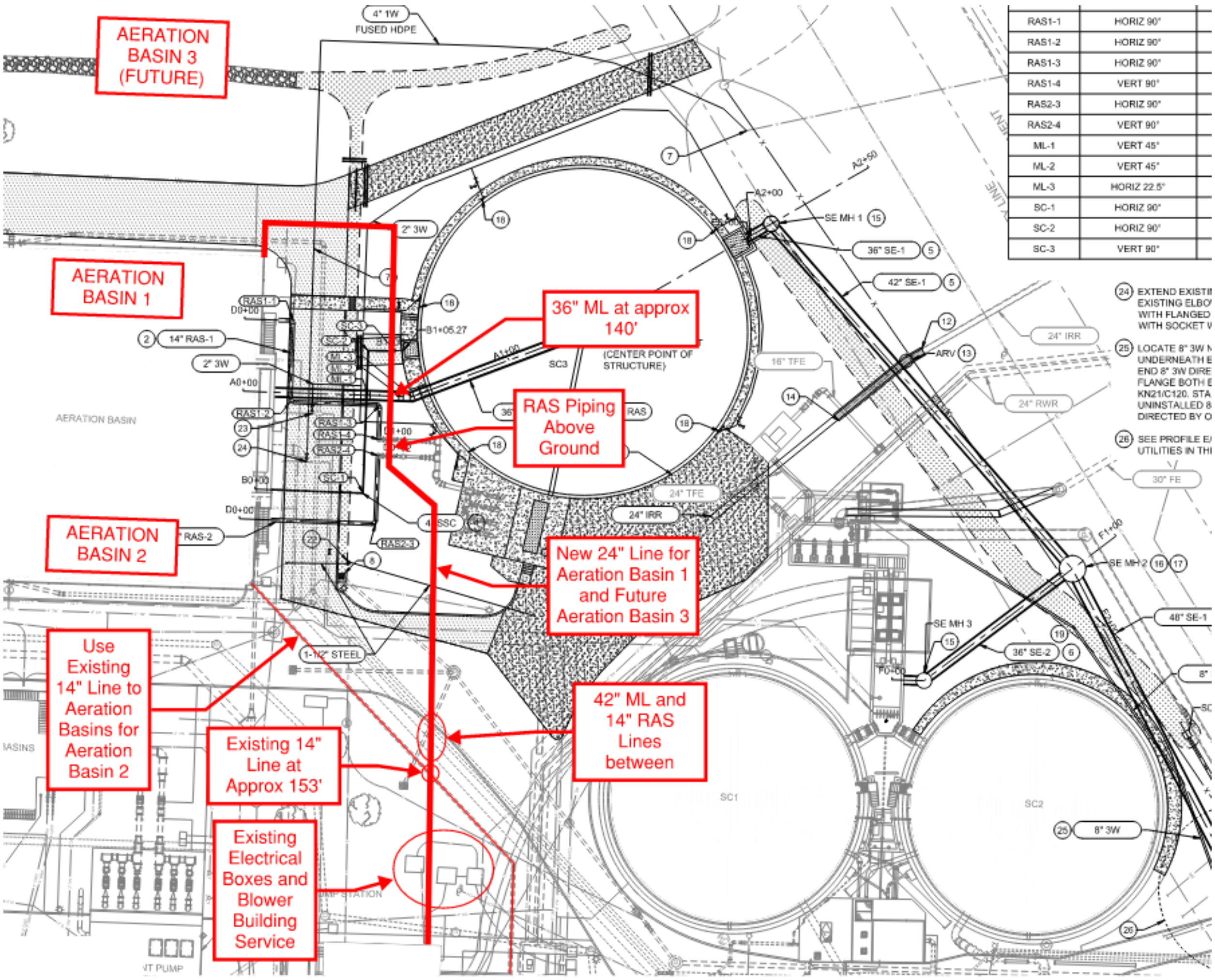

Figure 12.10 Air Distribution Piping Modifications

These modifications will maintain pipe velocities below the maximum velocity criterion throughout the system. Table 12.7 summarizes the impact of air distribution system Alternative 2 on the blower discharge pressure. With these modifications, the highest blower discharge pressures occur under the 2031/2035 peak conditions (up to 10 psi).

Table 12.7 Projected Air Flow Rate and Pressure for Air Distribution Piping Alternative 2

Condition	Current (2020/2024)				Secondary Capacity (2031/2035)				End of Planning Period (2045/2049)			
	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)
Minimum Day (DW)	1700	*0.6*	1700	8.5	1700	*0.6*	1700	8.5	2500	*0.6*	2500	8.5
Minimum Day (WW)	1700	*0.6*	2300	8.5	1700	*0.6*	2300	8.5	2500	*0.6*	3200	8.5
Average (DW)	3000	1.1	3000	8.6	3700	1.4	3700	8.7	4800	1.1	4800	8.6
Average (WW)	2000	0.8	2600	8.5	2300	0.9	2900	8.5	2700	*0.6*	3300	8.5
Maximum Month (DW)	5500	2.1	*6200*	8.9	*6700*	2.5	*7400*	9.1	**8600**	1.9	**9200**	8.9
Maximum Week (DW)	*6700*	2.5	*7300*	9.0	*8100*	3.1	**8800**	9.3	**10,300**	2.3	**11,000**	9.1
Maximum Day (DW)	*7800*	2.9	**8400**	9.2	**9500**	3.6	**10,100**	9.6	**12,100**	2.7	**12,700**	9.3
Peak Hour (DW)	**9100**	3.4	**9800**	9.5	**11,000**	**4.0**	**11,600**	*10.0*	**14,200**	3.2	**14,800**	9.6

Notes:
(1) The total air flow rate to the aeration basins. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).
(2) The minimum air flow rate per diffuser for Minimum Day (DW) and Minimum Day (WW) and the maximum air flow rate per diffuser otherwise. Values set in *blue italic* fall below the minimum air flow rate per diffuser or minimum air flow rate for mixing design criteria. Values set in **bold** exceed the maximum air flow rate per diffuser design criterion for the corresponding condition.
(3) The total air flow rate, equal to the sum of the total air flow rate to the aeration basins and air flow rate to the post-aeration diffusers. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).
(4) Estimated blower discharge pressure. Values set in *red italic* exceed the rated discharge pressure of the existing Lamson blowers (9.6 psi). Values set in **bold** exceed the rated discharge pressure of the existing Aerzen blowers (10 psi).

12.6.3 Alternative 3

The new large diameter yard piping required for Alternatives 1 and 2 constitutes a significant portion of the anticipated construction cost of both alternatives. Noise resulting from velocities exceeding the maximum threshold is less of a concern for buried piping due to ground dampening. Alternative 3 was therefore developed to evaluate system performance and blower requirements if the existing 14 inch diameter pipe from the blower building to the aeration basins is retained and used to deliver air to the two existing aeration basins as well as the future Aeration Basin 3. In addition to the changes noted above, the manifold pipe diameters were increased for Alternative 3 as follows:

- Aeration Basin 2 increased to 30 inches from 14 inches.
- Aeration Basin 1 increased to 24 inches from 10 inches.

These modifications will maintain pipe velocities below the maximum velocity criterion throughout the system. Table 12.8 summarizes the impact of air distribution system Alternative 3 on the blower discharge pressure. With these modifications, the blower discharge pressure occurs under the 2045/2049 peak conditions with a maximum of 10.9 psi.

Table 12.8 Projected Air Flow Rate and Pressure for Air Distribution Piping Alternative 3

Condition	Current (2020/2024)				Secondary Capacity (2031/2035)				End of Planning Period (2045/2049)			
	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)	ABs(1) (scfm)	Q/nd(2) (scfm)	Total(3) (scfm)	P(4) (psi)
Minimum Day (DW)	1700	*0.6*	1700	8.5	1700	*0.6*	1700	8.5	2500	*0.6*	2500	8.5
Minimum Day (WW)	1700	*0.6*	2300	8.5	1700	*0.6*	2300	8.5	2500	*0.6*	3200	8.5
Average (DW)	3000	1.1	3000	8.6	3700	1.4	3700	8.7	4800	1.1	4800	8.8
Average (WW)	2000	0.8	2600	8.5	2300	0.9	2900	8.5	2700	*0.6*	3300	8.5
Maximum Month (DW)	5500	2.1	*6200*	9.0	*6700*	2.5	*7400*	9.3	**8600**	1.9	**9200**	9.4
Maximum Week (DW)	*6700*	2.5	*7300*	9.3	*8100*	3.1	**8800**	*9.6*	**10,300**	2.3	**11,000**	*9.8*
Maximum Day (DW)	*7800*	2.9	**8400**	9.5	**9500**	3.6	**10,100**	**10.0**	**12,100**	2.7	**12,700**	**10.3**
Peak Hour (DW)	**9100**	3.4	**9800**	*9.9*	**11,000**	**4.0**	**11,600**	**10.5**	**14,200**	3.2	**14,800**	**10.9**

Notes:
(1) The total air flow rate to the aeration basins. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).
(2) The minimum air flow rate per diffuser for Minimum Day (DW) and Minimum Day (WW) and the maximum air flow rate per diffuser otherwise. Values set in *blue italic* fall below the minimum air flow rate per diffuser or minimum air flow rate for mixing design criteria. Values set in **bold** exceed the maximum air flow rate per diffuser design criterion for the corresponding condition.
(3) The total air flow rate, equal to the sum of the total air flow rate to the aeration basins and air flow rate to the post-aeration diffusers. Values set in *green italic* exceed the existing firm capacity of the blowers (largest blower out of service). Values set in **bold** exceed the existing installed capacity of the blowers (all units in service).
(4) Estimated blower discharge pressure. Values set in *red italic* exceed the rated discharge pressure of the existing Lamson blowers (9.6 psi). Values set in **bold** exceed the rated discharge pressure of the existing Aerzen blowers (10 psi).

12.6.4 Alternative Comparison

A comparison of the capital costs for the three air distribution piping alternatives is provided in Table 12.9. Details of the opinion of probable costs are included in Appendix 12B. The capital costs below reflect the costs to increase capacity to reach the 2031/2035 condition (Phase 1) as well as the costs to extend the air distribution piping to Aeration Basin 3 as part of the future secondary capacity expansion project (Phase 2). All air distribution piping alternatives terminated at a 30 inch elbow connected to the blower header at the blower building. Improvements to the blower header upstream of this fitting were included in the blower alternative comparison (discussed in Section 12.7). As shown in Table 12.9, the expected capital cost ranges for each alternative overlap, meaning they cannot be differentiated by cost at this stage. That said:

- The net present cost for Alternative 1 is the highest of the three alternatives.
- The net present cost is comparable between Alternatives 2 and 3.
- Alternative 1 carries the highest capital cost in both phases.
- The improvements (and therefore the capital cost) are the same for phase 2 of Alternatives 1 and 3.
- The capital costs are similar between Alternatives 2 and 3 in both phases.

Table 12.9 Opinion of Probable Project Costs for Air Distribution Piping Alternatives

Element	Alternative 1	Alternative 2	Alternative 3
Phase 1			
Demolition of Existing Piping	$86,000	$56,000	$66,000
Temporary Air Piping	$99,000	$9,900	$49,000
Yard Piping	$470,000	$700,000	$77,000
Process Integration	$2,000,000	$1,400,000	$1,900,000
EI&C	$450,000	$450,000	$450,000
Total Project Cost	**$3,100,000**	**$2,600,000**	**$2,500,000**
Expected Range(1)	**$1.5M to $6.1M**	**$1.3M to $5.2M**	**$1.3M to $5.0M**
Phase 2			
Demolition of Existing Piping	$0	$0	$0
Temporary Air Piping	$0	$0	$0
Yard Piping	$130,000	$84,000	$130,000
Process Integration	$770,000	$690,000	$820,000
EI&C	$210,000	$210,000	$210,000
Total Project Cost	**$1,100,000**	**$990,000**	**$1,200,000**
Expected Range(1)	**$0.56M to $2.2M**	**$0.49M to $2.0M**	**$0.58M to $2.3M**
Net Present Cost			
Phase 1	$2,900,000	$2,500,000	$2,400,000
Phase 2	$970,000	$860,000	$1,000,000
Total Net Present Project Cost	**$3,900,000**	**$3,400,000**	**$3,400,000**
Expected Range(1)	**$2.0M to $7.8M**	**$1.7M to $6.7M**	**$1.7M to $6.9M**

Notes:
(1) Class 5 costs per American Association of Cost Engineers have an expected accuracy range of -50 % to +100 %.
EI&C - electrical, instrumentation, and control.

The required blower header pressure is higher in Alternative 3, which will result in higher operating costs compared to the other alternatives. This higher pressure occurs under the infrequent peak flow conditions with the blower header pressure in Alternative 3 being marginally higher relative to Alternatives 1 and 2 under the more frequent average and maximum month conditions. A 25-year life cycle cost comparison (from the 2020/2024 condition through the 2045/2049 condition) for the power consumption in the three alternatives was prepared assuming typical wire-to-air efficiencies for the three blower technologies advanced to alternatives analysis (discussed below). Details of the analysis are included in Appendix 12B. The results are summarized in Table 12.10. As shown:

- Alternative 1 has the highest net present power consumption cost. Alternative 2 is slightly lower.
- The difference in net present cost between Alternative 1 and 3 is an order of magnitude lower than the difference in net present capital cost between the alternatives. As such, the differential header pressure between these alternatives has a negligible impact on the comparison.

Table 12.10 Net Present 25-Year Power Consumption Cost

Alternative	Hybrid Blower Wire-to-air = 66 percent	High-Speed Turbo Wire-to-air = 71 percent	Single-Stage Geared Wire-to-air = 79 percent
Alternative 1	$1,740,000	$1,620,000	$1,450,000
Alternative 2	$1,740,000	$1,620,000	$1,460,000
Alternative 3	$1,760,000	$1,640,000	$1,470,000
Difference (Alternative 3 to 1)	**$24,000**	**$23,000**	**$20,000**

Based on this analysis of air distribution piping alternatives, it is recommended that Alternatives 2 and 3 be carried forward into predesign:

- The capital costs are comparable between these alternatives in both phases. Refinement during predesign would be needed to more definitively differentiate these alternatives.
- Construction sequencing is expected to be easier with Alternative 2 than 3; however, significant yard piping will be required for Alternative 2. This is currently routed through the congested area between the existing aeration basins and secondary clarifiers. An initial check of the profiles of the existing infrastructure indicates the current routing is feasible; this routing should be refined as part of predesign. Alternative pipe routing should be considered as well.
- Additionally, a fourth aeration basin will be required after the end of the current planning period but prior to buildout based on the current flow and load projections. This expansion would be more easily accommodated with Alternative 2 than 3. This should be examined further during predesign.
- Importantly, this recommendation to carry forward Alternatives 2 and 3 assumes that the existing 14 in line from the blower building to the aeration basins is and will remain in good condition. If this is not the case, replacement of the line may be warranted.

12.7 Blower Technologies and Alternatives

This section outlines the blower technologies and alternatives considered to satisfy the air flow projections developed for the diffuser grid modifications summarized in Table 12.5. Blower alternatives were developed based on the design criteria summarized in Appendix 12A with the following assumptions:

- Blower capacity would be expanded in two phases (consistent with the air distribution piping alternatives):
  - Phase 1: Initial project to provide blower capacity for the 2031/2035 condition when secondary treatment capacity will be reached.
  - Phase 2: Second project as part of the secondary treatment capacity expansion project to provide capacity through at least the end of the planning period (2045/2049).
  - Phasing blower capacity expansion is recommended due to the uncertainty in the air flow rate projections. By phasing capacity addition, the District will be able to:
    - Collect process data under the altered operation at the Forest Grove WRRF to improve process model and air flow rate estimate accuracy.
    - Refine blower coverage and right-size the blowers overall as part of the secondary treatment expansion project.
- Blowers in both phases would be located in the existing blower building.

- The existing electrical service will be sufficient to supply the blowers. Historically, the main control centers served a combined 1000 hp in blower motor. The total power draw is projected to be up to 1050 hp with all units in service.
- Selected blower size and turndown need to provide overlapping coverage over the anticipated operating range.
- Blower cycling to match the range of diurnal air flow rates under average and maximum month conditions should be minimized.

12.7.1 Blower Technology Description and Screening

Rotary lobe, rotary screw, multistage centrifugal, single-stage geared centrifugal, and high-speed turbo blower technologies were considered as alternatives for the blower improvement projects. The following subsections outline the benefits and limitations of each technology.

12.7.1.1 Rotary Lobe

Rotary lobe blowers, shown in Figure 12.11, are the simplest type with two rotors (lobes) placed axially parallel to each other and centered within a housing. The most recent models include tri-lobe and hybrid designs. The rotors revolve displacing a known volume of air, and timing gears ensure that the rotors do not make contact. Positive displacement (PD) blowers are typically used for smaller applications, although models are available with capacities up to 6,000 cubic feet per minute (cfm). Typical discharge pressures range from 1 pound per square inch, gauge (psig) to 15 psig. Major manufacturers supplying PD blowers for the wastewater market include Dresser-Roots, Aerzen, Kaeser, and Gardner-Denver Sutorbilt.

The advantages of PD blowers for the present application include their relatively low capital cost and their typically simple controls. PD blowers are best suited for applications with a wide range of side water depths. However, the aeration basins at the Forest Grove WRRF are operated at a relatively constant side water depth. PD blowers are considerably less efficient than centrifugal blowers, require a higher level of maintenance, and produce higher noise and vibration levels as compared to their centrifugal counterparts.

Figure 12.11 Positive Displacement Blowers

12.7.1.2 Rotary Screw Blowers

Three of the five existing blowers at the Forest Grove WRRF are hybrid rotary screw blowers (shown in Figure 12.12). Rotary screw blowers compress air within the blower block by squeezing air within the decreasing volume between two rotors spinning in opposite directions. Advantages of screw blowers include favorable turn down ratios (3:1 to 4:1), adaptability to pressure and temperature changes, constant airflow with changing discharge pressure (stable operation), and low maintenance requirements.

Similar to rotary lobe blowers, rotary screw blowers are typically housed within an acoustical enclosure. Access is from the front and back of the units, allowing them to be located side by side. Manufacturers of rotary lobe blowers include Kaeser, Atlas Copco, and Gardner-Denver. Aerzen manufactures a hybrid blower that consists of twisted lobe rotors, which have similar efficiency and turndown as rotary screw blowers. Current offerings from these manufactures provide maximum nominal flow rates on the order of 5000 cfm, which means the largest units in these series would be required for the current application.

Figure 12.12 Existing Rotary Screw Blowers at the Forest Grove WRRF

12.7.1.3 Multistage Centrifugal Blowers

Two of the five existing blowers at the Forest Grove WRRF are multistage centrifugal (MSC) blowers (shown in Figure 12.13). MSC blowers have two or more impellers fixed to a shaft that rotates within a housing. Impellers, or stages, are typically added to meet the design discharge pressures. The housing is arranged to lead the air from the discharge of one impeller to the inlet of the next impeller, which in effect is like several single-stage units connected in series.

MSC blowers are the most used type for municipal wastewater treatment, particularly for medium size wastewater treatment facilities. Units are available with capacities from 100 cfm to 40,000 cfm, and discharge pressures of 1 psig to 12 psig. MSC blowers are a robust technology, and a relatively low capital cost. Traditionally, inlet throttling valves provided a relatively wide airflow turndown capability albeit with reduced efficiency. Major manufacturers supply MSC blowers for the municipal wastewater market includes Gardner-Denver (formerly Hoffman and Lamson), Spencer, Atlas-Copco, Continental, and Hibon.

Figure 12.13 Existing Multistage Centrifugal Blowers at the Forest Grove WRRF

12.7.1.4 Single-Stage Geared Centrifugal Blowers

Single-stage geared centrifugal blowers (shown in Figure 12.14) are constant-speed, integrally geared packaged blower systems. The blower package consists of a single-stage geared centrifugal blower with inlet guide vanes and variable discharge diffusers, electric motor, oil lube system, cooling water system, and instrumentation and controls system. Depending on the size of the unit, components can either be mounted on a single skid at the factory by the blower manufacturer or provided as individual components assembled at the project site. Other factors that could impact pre-assembly include requirements for testing the blower with the job motor, size of units and freight weight limitations, timing of fabrication, etc. A pressure differential between the blower inlet and discharge is developed, and can be considered constant pressure, variable volume units. The blower capacity is varied by modulating the inlet guide vanes and discharge diffusers. Major manufacturers of this technology include Howden (includes Turblex and HV-Turbo), Atlas-Copco, Lone Star, and Next Turbo.

Single-stage blowers offer many advantages, including the ability to operate across a wide range of capacities (40 percent to 100 percent) while maintaining high efficiencies across the entire operating band, and a large installation base across the United States. However, these blowers are generally only used in applications with high air flow rates and carry a higher capital cost.

Figure 12.14 Single-Stage Geared Centrifugal Blowers

12.7.1.5 High-Speed Turbo Blowers

The District has installed high-speed turbo blowers at the Durham and Rock Creek WRRFs. High-speed turbo blowers are a technology that consists of a centrifugal impeller driven by a high-speed electric motor (running at between 20,000 and 30,000 revolutions per minute) through a variable frequency drive (VFD). The units are compact and come as a packaged system including a blower, motor, VFD, control panel, vibration isolators, and ancillary components installed in a compact sound-attenuating enclosure (see Figure 12.15). Because of these and other factors, high-speed turbo blowers can operate at higher efficiencies than multistage centrifugal blowers and similar efficiencies as single-stage geared centrifugal blowers; however, they are generally lower due to unavoidable losses from the VFD and lack of dual point control. Major manufacturers include APG Neuros, Atlas Copco, Aerzen, and Sulzer ABS/HST. Although similar in principle, there are distinct mechanical and electrical component differences between each manufacturer's design, including bearings, impeller, enclosure, motor, and VFD. This may pose problems with sourcing replacement parts as units age and manufacturers make product lines obsolete.

Figure 12.15 High-Speed Turbo Blower at the Durham AWRRF (Right-Most Unit Depicted)

12.7.1.6 Blower Technology Screening

Table 12.11 compares the primary features of the five blower technologies, together with a qualitative summary of relative advantages and disadvantages of each technology for this application. These were weighed to identify a subset of blower technologies that are recommended for comparative evaluation in preliminary design of Phase 1. As shown:

- Rotary lobe and multistage centrifugal blowers are not recommended for further consideration due to their lower efficiency.
- Rotary screw and high-speed turbo technologies are recommended for further consideration based on their comparatively high efficiency, small footprint, and the District's experience.
- Single-stage geared centrifugal blowers are also recommended for further consideration based on their high efficiency.

Table 12.11 Comparison of Blower Technologies

Blower Type	Nominal Blower Efficiency	Nominal Turndown (%)[1]	Typical Discharge Pressure (psig)	Qualitative Surge Sensitivity (0 to 3)	Representative Manufacturers	General Relative Advantages	General Relative Disadvantages	Carried Forward
Rotary Lobe	45 to 65	40 to 50	1 to 15	0	▪ Aerzen ▪ Dresser-Roots ▪ Gardner-Denver ▪ Kaeser	▪ Steep pump curve ▪ Lower cost ▪ Simple controls	▪ Lower efficiency ▪ Higher maintenance ▪ Higher noise and vibration	No, due to lower efficiency
Rotary Screw	55 to 75	40 to 50	1 to 15	0	▪ Aerzen ▪ Kaeser	▪ District experience	▪ Higher cost	**Yes**
Multistage Centrifugal	55 to 75	50 to 60	1 to 12	1	▪ Atlas-Copco[2] ▪ Continental ▪ Gardner-Denver ▪ Hibon ▪ Spencer	▪ Lower cost ▪ Simple controls ▪ District experience	▪ Large footprint ▪ Lower efficiency	No, due to lower efficiency
Single-Stage Geared Centrifugal	80 to 85	40 to 55	5 to 30	2	▪ Atlas-Copco[2] ▪ Howden/Turblex ▪ Lone Star ▪ Next Turbo	▪ High efficiency ▪ Combination control	▪ Large footprint ▪ Higher maintenance ▪ Higher cost	**Yes**
High-Speed Turbo	75 to 85	45 to 55	6 to 16	3	▪ Aerzen ▪ APG Neuros ▪ Atlas Copco[2] ▪ Kaeser ▪ Sulzer ABS/HST	▪ High efficiency ▪ Small footprint ▪ Low maintenance ▪ District experience	▪ More complex controls ▪ Higher cost	**Yes**

Notes:
(1) Nominal turndown expressed as a percent of the rated capacity.
(2) Recent experience suggests Atlas Copco may be hesitant to provide proposals for the municipal wastewater market.

12.7.2 Blower Alternatives

Based on the blower technology screening, proposals were solicited from blower manufacturers for rotary screw, high-speed turbo, and single-stage geared centrifugal blowers. Representative manufactures were selected for each technology (Aerzen for hybrid rotary screw and high-speed turbo, APG-Neuros for high-speed turbo, and Howden for single-stage geared centrifugal) and provided with the air flow rate ranges and design criteria described above. The proposals are summarized in Table 12.12.

Table 12.12 Blower Alternative Comparison

Parameter	Units	Aerzen Hybrid Rotary Screw	Aerzen High-Speed Turbo	APG-Neuros High-Speed Turbo	Howden-Turblex Single-Stage Geared Centrifugal
Blower dimensions (each, H x W x D)(1)	inches	**112** x **83** x **93**	AT200: 65 x 73 x 53 AT300: 89 x 97 x 81	NX300D: 90 x 101 x 59 NX300S: 105 x 100 x 55	89 x 65 x 166
Blower mass (each)	lb	**9165**	AT200: 2605 AT300: **6030**	NX300D: 4426 NX300S: 4731	4630
Clearance required (each)	inches	**32**	42	42	26
Inlet connection (each)		Ventilated cabinet	AT200: 16 inch flange AT300: 20 inch flange	NX300D: 20 inch flange NX300S: 18 inch flange	Inlet filter/silencer assembly
Discharge connection (each)		12 inch flange	AT200: 12 inch flange AT300: 16 inch flange	NX300D: 10 inch flange NX300S: 12 inch flange	12 inch, 14 inch, or 16 inch flange
Blower efficiency(2)	%	79 to 82	76 to 80	80 to 85	85
Wire-to-air efficiency(2)	%	65 to 67	68 to 71	71 to 75	79
Nominal turndown(3)	%	33	AT200: 50 AT300: 50	NX300D: 30 NX200S: 50	40
Phase 1					
Model (quantity)		D 152S (4)	AT200-0.8S (2) AT300-0.8T (2)	NX300D (1) NX300S (3)	KA5SV-GK200 (4)
Total nameplate power	hp	1200	1000	1200	800
Rated flow per blower	scfm	4 x 4,700	2 x 3,750 and 2 x 5,400	1 x 5,600(4) and 3 x 5,300	4 x 4,000
Nominal minimum flow	scfm	1540	1950	1190	1600
Firm nominal flow	scfm	14,000	12,900	16,000	12,000
Blower package cost		$780,000	$770,000	$781,800	$1,288,00(5)

Parameter	Units	Aerzen Hybrid Rotary Screw	Aerzen High-Speed Turbo	APG-Neuros High-Speed Turbo	Howden-Turblex Single-Stage Geared Centrifugal
Phase 2					
Model (quantity)		D 152S (5)	AT200-0.8S (2) AT300-0.8T (3)	NX300D (1) NX300S (3)	KA5SV-GK200 (5)
Total nameplate power	hp	1500	1300	1200	1200
Rated flow per blower	scfm	5 x 4,700	2 x 3,750 and 3 x 5,400	1 x 5,600 and 3 x 5,300	5 x 4,000
Nominal minimum flow	scfm	1540	1950	1190	1600
Firm nominal flow	scfm	19,000	18,300	16,000	16,000
Blower package cost		$200,000	$225,000	$0(6)	$322,000(5)

Notes:
(1) Values set in **bold** denote dimensions that are too large for the existing blower building.
(2) Ranges under the average wet and dry weather conditions. Estimated blower efficiencies from the vendor-provided performance data or expected efficiency based on technology. Wire-to-air efficiency includes the estimated blower efficiency, motor efficiency of 95 % and the following as applicable: VFD efficiency of 96% and belt efficiency of 98%.
(3) Nominal turndown expressed as a percent of rated capacity based on values reported by blower manufacturers.
(4) The APG-Neuros NX300D is a dual core blower.
(5) The maximum of the provided cost range was adopted for Phase 1. This cost was divided by four for Phase 2.
(6) No expansion required for Phase 2 with the APG-Neuros High-Speed Turbo alternative.

12.7.2.1 Hybrid Rotary Screw Blower Alternative

The D152S is Aerzen's largest hybrid rotary screw blower with a maximum capacity of 4700 scfm under the projected peak conditions. The second largest blower in the series has a nominal maximum capacity of less than 4000 scfm. With these capacities straddling the design point, Aerzen proposed using the D152S, which results in a solution that has more capacity than required. This is evident in the nominal blower coverage map for this alternative shown in Figure 12.16. As shown, approximately 4000 scfm of surplus capacity is provided at the 2045/2049 peak hour condition.

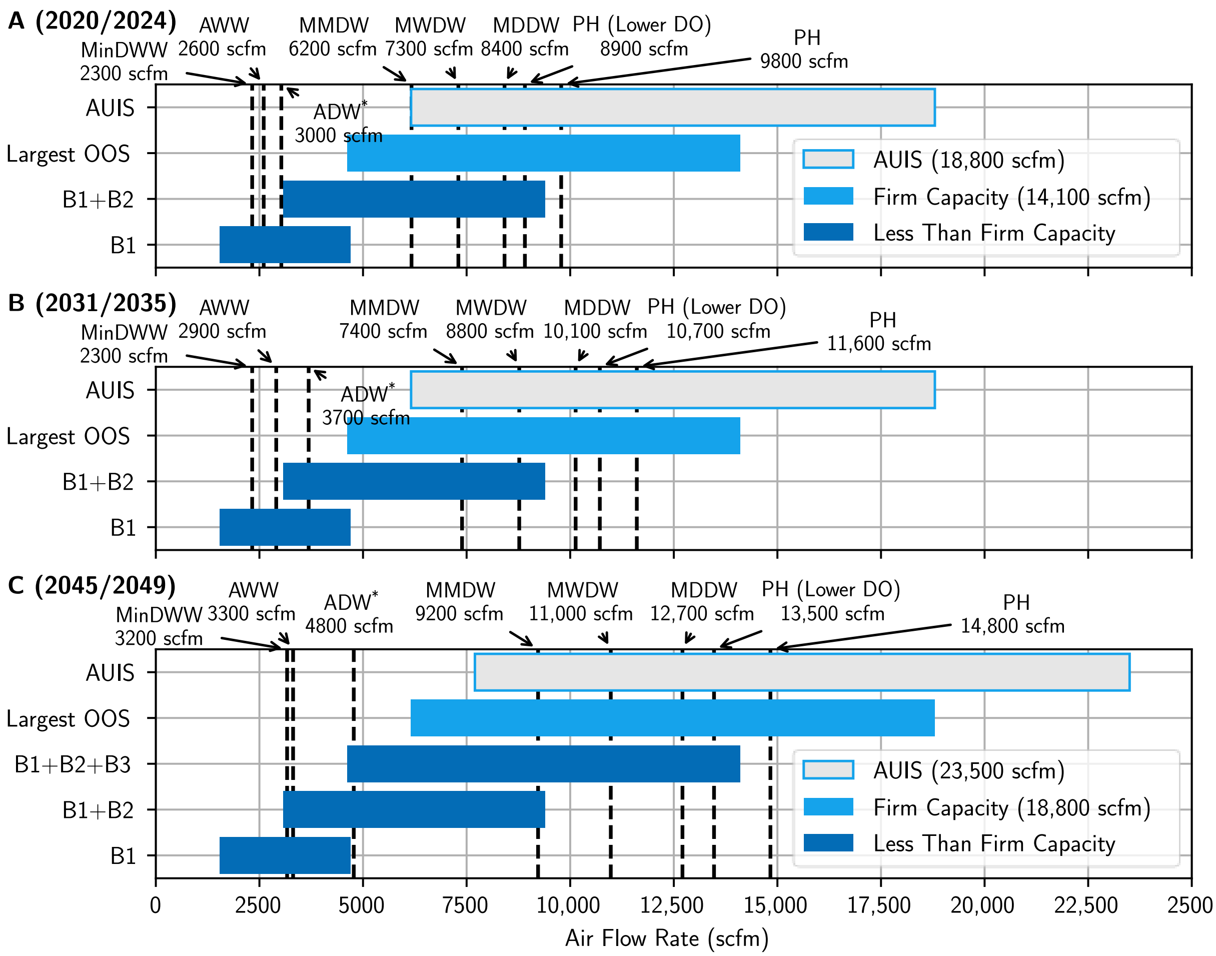

Figure 12.16 Aerzen Hybrid Rotary Screw Blower Alternative Blower Coverage Map.

Blower Building Layout

A major consideration in comparing the blower alternatives is whether the existing blower building can be used through the planning period. To address this, a blower layout was developed for this alternative using the minimum clearances in Table 12.12 and assuming 42 inches between blowers. This is shown in Figure 12.17. To accommodate the flexible coupling and check valve on the discharge, more than the minimum 32 inches shown in Figure 12.17 between the south wall and the blowers is needed. Figure 12.18

shows the blower building section with the 4 feet 7 inches of space. From this analysis, the Aerzen hybrid rotary screw blowers will not fit in the existing blower building for the following reasons:

- Each blower weighs 9200 pounds (4.6 ton) which exceeds the existing roof hoist capacity (3 ton).
- Even if replaced, the floor to ceiling height (approximately 15 feet 9 inches) is too low to allow the new blowers to be moved with the ceiling hoist (the height of two blowers is 15 feet 6 inches).
- The inside clear width of the building (approximately 18 feet 5 inches between the wide flange columns) is too narrow to allow a blower to be maneuvered around an installed blower. A minimum width of 18 feet 11 inches would be required.
- Air is discharged horizontally from the base of the cabinet. The space required for a flange, expansion joint, and elbow needed to connect to the blower header will require at least 45 inches of additional clearance. This would require the blower header to be located outside the blower building (as shown in Figure 12.17 and Figure 12.18).

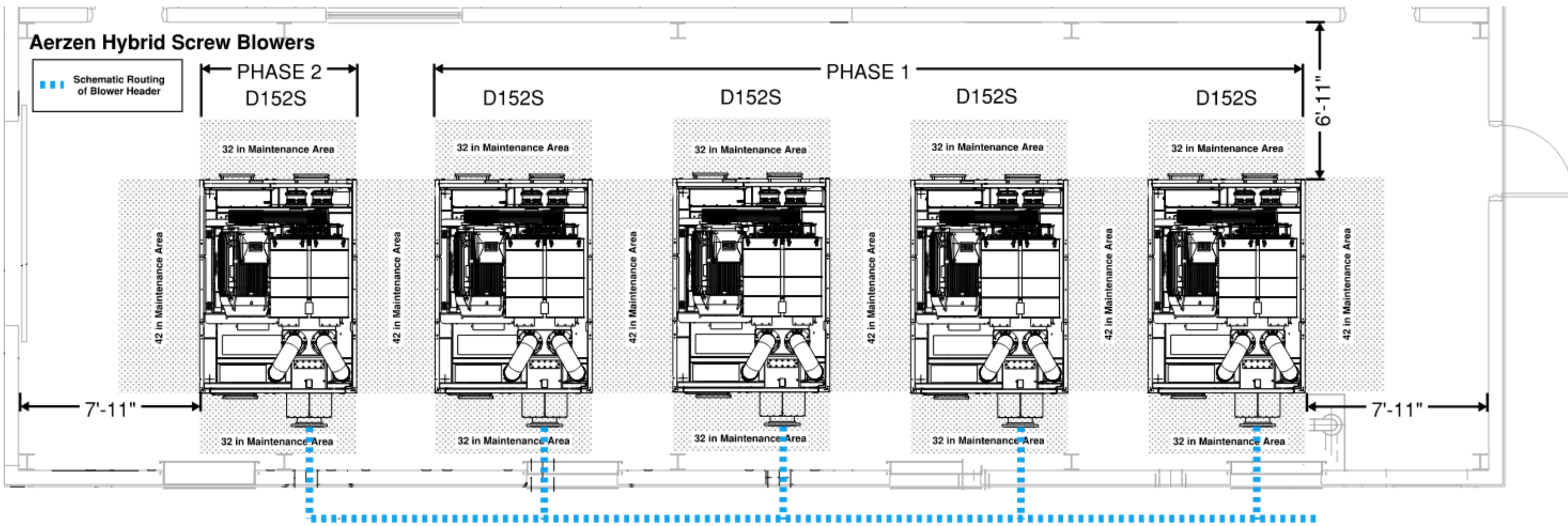

Figure 12.17 Hybrid Rotary Screw Blower Alternative Blower Room Plan

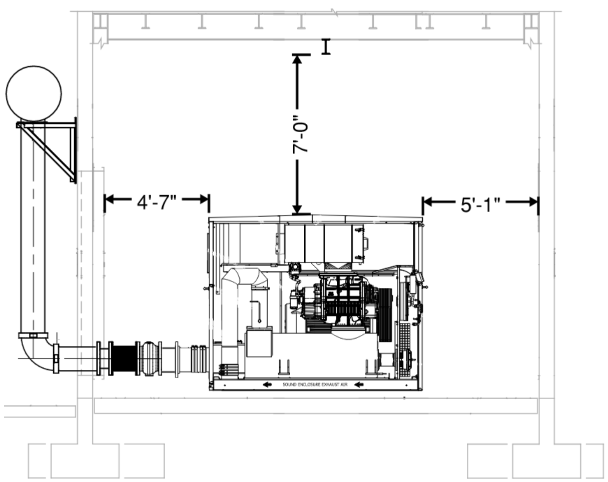

Figure 12.18 Hybrid Rotary Screw Blower Alternative Blower Room Section

Despite not fitting in the existing blower building, this alternative was carried forward as representative of the blower technology for subsequent comparisons. Other manufacturers may have hybrid screw offerings that may fit within the blower building. Offerings in Kaeser's CBS-HBS series have similar capacities to Aerzen's Delta Hybrid series; however, its largest blower (the HBS 1600) may be able to deliver 5000 scfm at the design condition. While the HBS 1600 is shorter than the D152S, it would still be difficult to fit these blowers in the existing blower building as they are approximately 3 feet longer than the D152S and weigh up to 13,200 pounds (6.6 ton).

Other Considerations

The Aerzen hybrid rotary screw blowers draw air through the cabinet, rather than dedicated inlet piping. Sufficient blower building ventilation is needed to supply the process air and maintain blower building temperature below the maximum for Delta Hybrid blowers (approximately 50 degree Celsius). At the 2045/2049 peak condition, the total required process air flow rate will exceed the process air flow rate for which the existing blower building ventilation was likely designed for (assumed to be the nominal total capacity of the original Lamson blowers at approximately 10,000 scfm). As such, it was assumed that additional ventilation would be required to supply the process air and manage the blower room temperature.

Wire-to-air efficiency dictates blower power consumption which represents the largest operating cost for the blowers. As shown in Table 12.12, the wire-to-air efficiency of the hybrid rotary screw blowers under the average wet weather and average dry weather conditions is the lowest of the blower alternatives evaluated. This is expected as these blowers have losses (e.g., V-belt and VFD) that are not incurred by other technologies.

Anticipated routine blower maintenance for the D152S blowers includes inspections, drive motor lubrication, air filter replacement, oil and filter replacement, and belt replacement. Additionally, Aerzen recommends specialized inspections and servicing every 30,000 to 40,000 hours. Bearing replacements or blower stage rebuilds are not anticipated during the life of the blower if proper maintenance is performed and design conditions are not exceeded.

12.7.2.2 High-Speed Turbo Blower Alternative

Proposals were solicited from Aerzen and APG-Neuros for high-speed turbo blowers. Aerzen recommended the AT200-08.S G5 and AT300-0.8T G5 blowers, which are able to deliver approximately 3750 scfm and 5400 scfm, respectively, under peak conditions. The resulting blower coverage map is depicted in Figure 12.19. As shown, this arrangement provides approximately 3500 scfm of surplus capacity at the 2045/2049 peak hour condition.

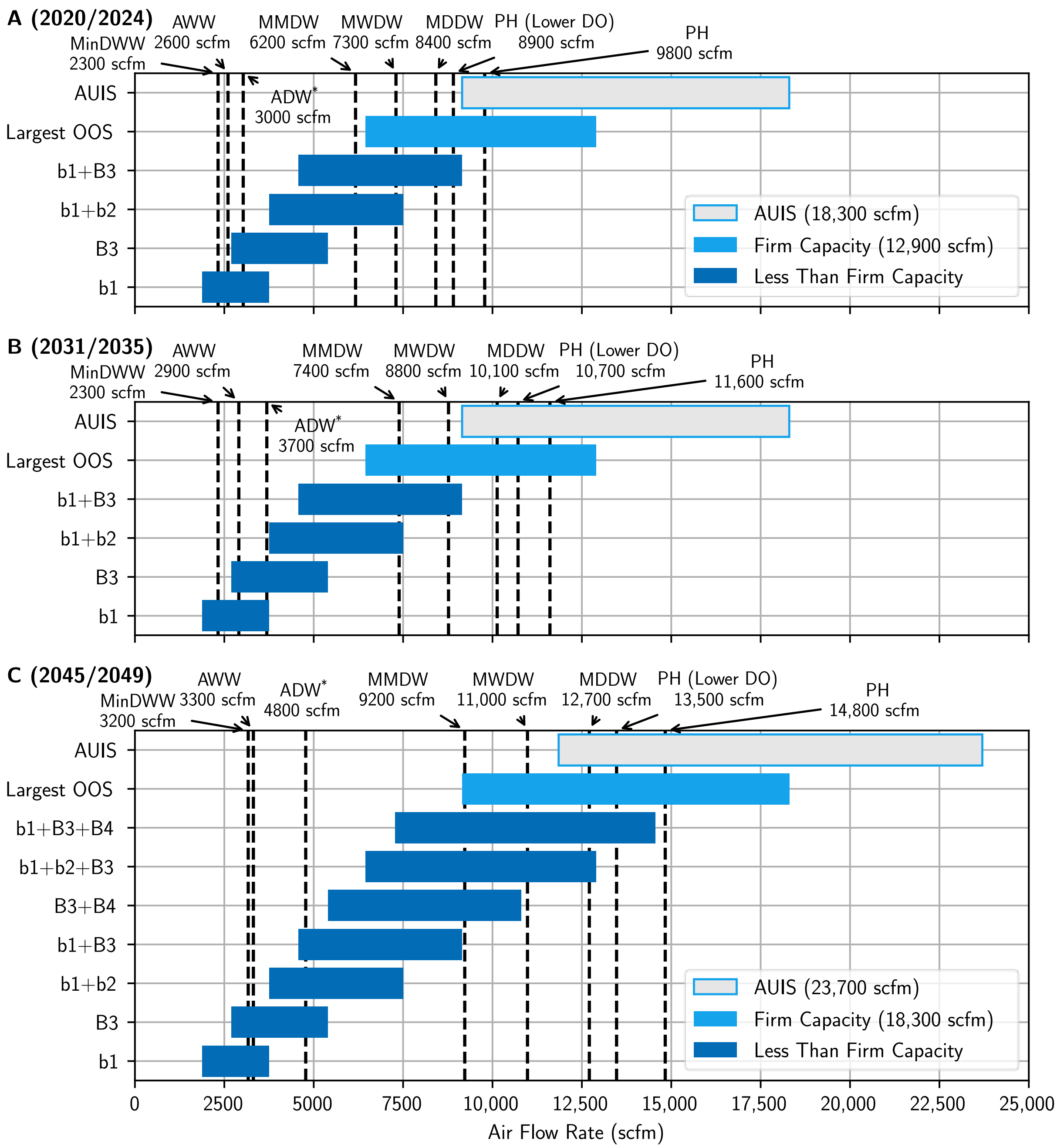

Figure 12.19 Aerzen High Speed Turbo Blower Alternative Blower Coverage Map.

Blowers b1 and b2 denote the smaller AT200 blowers. Blowers B3, B4, and B5 denote the larger AT300 blowers.

APG-Neuros proposed a single blower configuration that would satisfy the air flow requirements for the 2031/2035 and 2045/2049 conditions. This proposal included single and dual core blowers (NX300S-C080 and NX300D-C070, respectively) to deliver the design air flow rates. These blowers can deliver approximately 5300 scfm and 5600 scfm, respectively, under the peak design conditions. With two cores, the NX300D-C070 can achieve turndown to less than 30 percent of the unit's nominal maximum. The resulting blower coverage map is depicted in Figure 12.20. As shown, the firm capacity at the 2045/2049 peak hour condition provides less surplus capacity (approximately 1200 scfm) than the Aerzen high speed turbo alternative. Importantly, this arrangement would likely have a disproportionately large runtime for the largest blower in the complement. The dual core blower has both the highest nominal capacity and the greatest turndown of the blowers proposed. As shown in Figure 12.20, the dual core would likely be the sole blower running most of the time until the 2031/2035 condition. To balance wear across the blowers, the other blowers would need to be exercised throughout the year; however, they may not have the turndown capacity to deliver the minimum air flow rates without overaerating, particularly prior to the 2031/2035 condition. Alternatively, a second dual core blower could be installed in lieu of one of the three single core blowers to provide redundancy under low air flow conditions and balance run times.

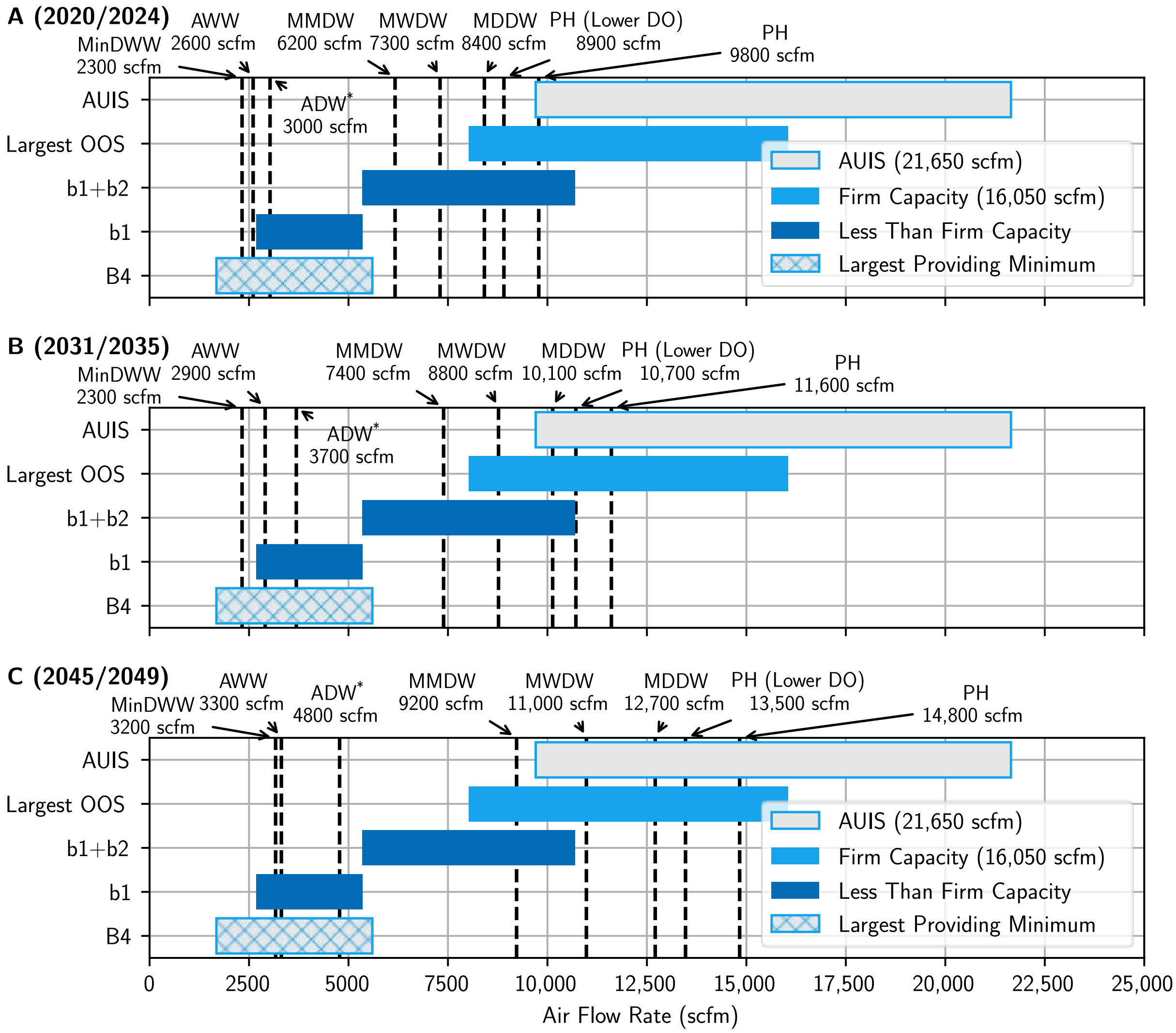

Figure 12.20 APG-Neuros High Speed Turbo Blower Alternative Blower Coverage Map

Blowers b1, b2, and b3 denote the single core NX300S blowers. Blower B4 denotes the dual core NX300D.

Blower Building Layouts

Blower room layouts were developed for both the Aerzen and APG-Neuros high speed turbo blower alternatives and are depicted in Figure 12.21. As shown, both alternatives can fit in the existing blower building. For the Aerzen alternative, the existing ceiling hoist capacity (3 ton) may be insufficient to move the AT300 blowers (weighing approximately 3 ton) and would need to be verified. Additionally, vertical clearance may be tight if this method is used to move the blowers. Importantly, there is likely sufficient space to allow for a mobile gantry to be used to move the AT300 blowers. The mass and size of the blowers in the APG-Neuros alternative are small enough that it may be possible to use either method for moving blowers.

Both high speed turbo blowers have flanged inlet piping connections. Neither provider included inlet silencers or prefilters in their proposals; however, it was assumed that these would be included and located outside the blower building similar to the configuration of the existing Aerzen blowers. An allowance of $15,000 was included for the silencer/inlet filter assembly for each blower. The inlet piping and silencer locations are depicted in the blower room plan (Figure 12.21) and in the blower room section (Figure 12.22).

Other Considerations

For high-speed turbo blowers, it is recommended that manufacturer-provided master control panels be used to coordinate individual blower operation with SCADA. This provides a more robust control solution to address the sensitivity of high-speed turbo blowers to surge conditions. An allowance of $75,000 was included in the cost estimates for these alternatives as this was not included in either proposal.

Both high-speed turbo blower alternatives use dedicated inlet piping that will draw air from outside the blower building. As such, additional ventilation will not be required to supply the process air. However, the temperature in the blower room may be higher due to the additional blower power installed. It was assumed that the existing louvers would provide sufficient air and that a new sidewall fan would be required.

As shown in Table 12.12, the wire-to-air efficiencies under average wet and dry weather conditions are similar for both high-speed turbo alternatives. For consistency, an additional loss of 4 percent was applied to the wire-to-air efficiencies in the APG-Neuros alternative. These wire-to-air efficiencies are in the range expected and are between those for the hybrid screw and single stage geared centrifugal.

Maintenance requirements for the two alternatives were developed from manufacture recommendations and prior experience with these units. These requirements include:

- Aerzen: The Aerzen turbo blowers have recommended annual inspections for the life of the blower. Maintenance includes replacement of filters (1st stage and 2nd stage) by District staff and periodic replacement and service of other equipment by an Aerzen service technician, including motors and bearings, capacitor exchange/inverter and control panel electronics, central processing unit controller, VFD controller, and human machine interface terminal.
- APG Neuros: The APG Neuros blowers are designed for continuous operation (On-Condition Maintenance) with a few scheduled inspections or repairs. Maintenance recommended by APG Neuros is limited to inlet air filter and water coolant changes by District staff. In the life cycle analysis discussed below, a lump sum allowance of $20,000 was applied at a 10-year interval to account for unanticipated component maintenance and replacement costs.

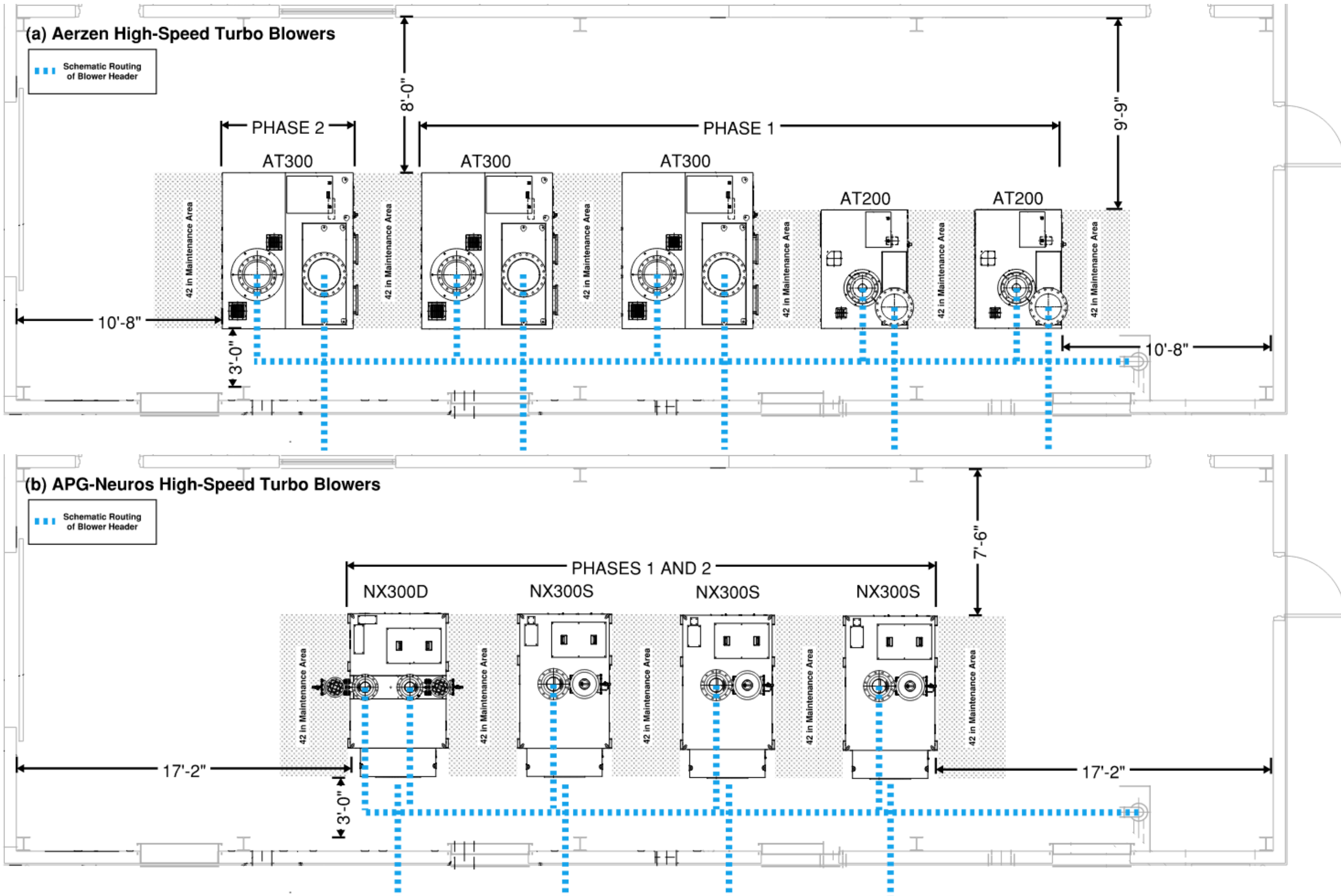

Figure 12.21 High Speed Turbo Blower Alternative Blower Room Plans.

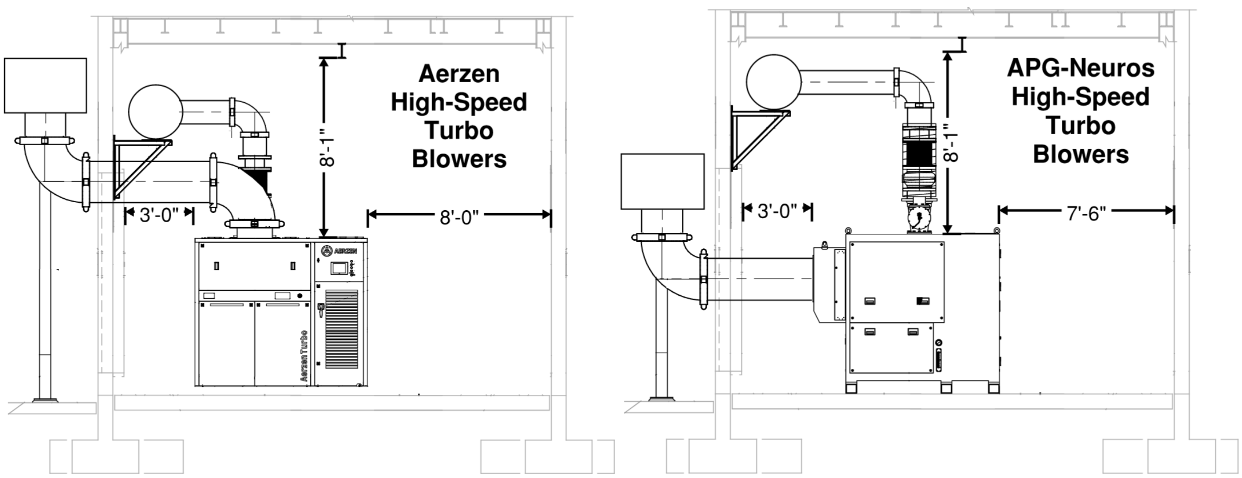

Figure 12.22 High Speed Turbo Blower Alternative Blower Room Sections.

12.7.2.3 Single Stage Geared Centrifugal Blower Alternative

The single stage geared centrifugal blower proposal from Howden provided four KA5SV-GK200 blowers for Phase 1, each with a nominal capacity of 4000 scfm under the peak design conditions. These blowers can achieve turndown of approximately 40 percent. The resulting blower coverage map is depicted in Figure 12.23. As shown, this arrangement provides approximately 1200 scfm of surplus capacity under the 2045/2049 peak hour condition.

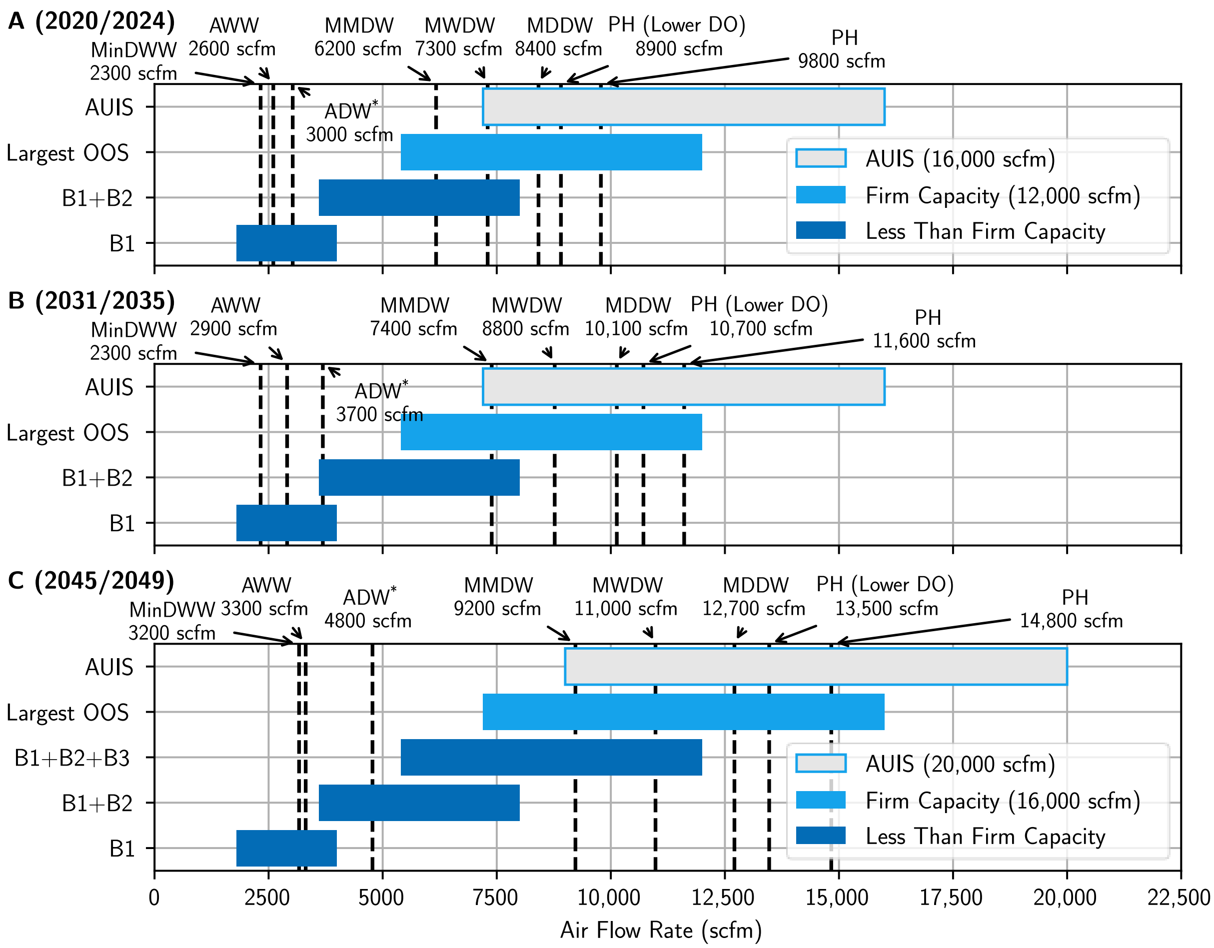

Figure 12.23 Howden Single-Stage Geared Centrifugal Blower Coverage Map

Blower Building Layout

The preliminary blower room layout developed for this alternative is depicted in Figure 12.24 and Figure 12.25, respectively. As shown, the blowers will likely fit into the existing blower building. Importantly, this layout is based on a minimum 42 inch clearance between the units with a 6 foot walkway along the north wall. As laid out, the inlet filter assembly interferes with the existing interior wide flange structural steel frame and clearance between blow off silencers and neighboring blower is tight.

Other Considerations

The blower room layout was developed so that the inlet filter assemblies would draw process air through louvers in the south wall. Additional openings and a new fan were included to provide sufficient ventilation for blower room temperature control.

The blower efficiencies reported by Howden were lower than anticipated for this technology, which can modulate inlet guide vanes and outlet diffusers to control flow while maintaining high efficiencies. This will need to be clarified with Howden. For the present analysis, a more typical blower efficiency of 85 percent was assumed. Importantly, this did not alter the conclusion from the life cycle analysis (below).

The single-stage geared centrifugal blower (KA5SV-GK200) from Turblex/Howden has recommended routine, annual, and special inspections for the life of the blower. Maintenance includes replacement of filters (oil and inlet), inlet silencer cleaning, butterfly valve cycling, and regular oil changes. Turblex/Howden recommends 2 levels of specialized service inspections after the first 24,000 and 48,000 hours of operation.

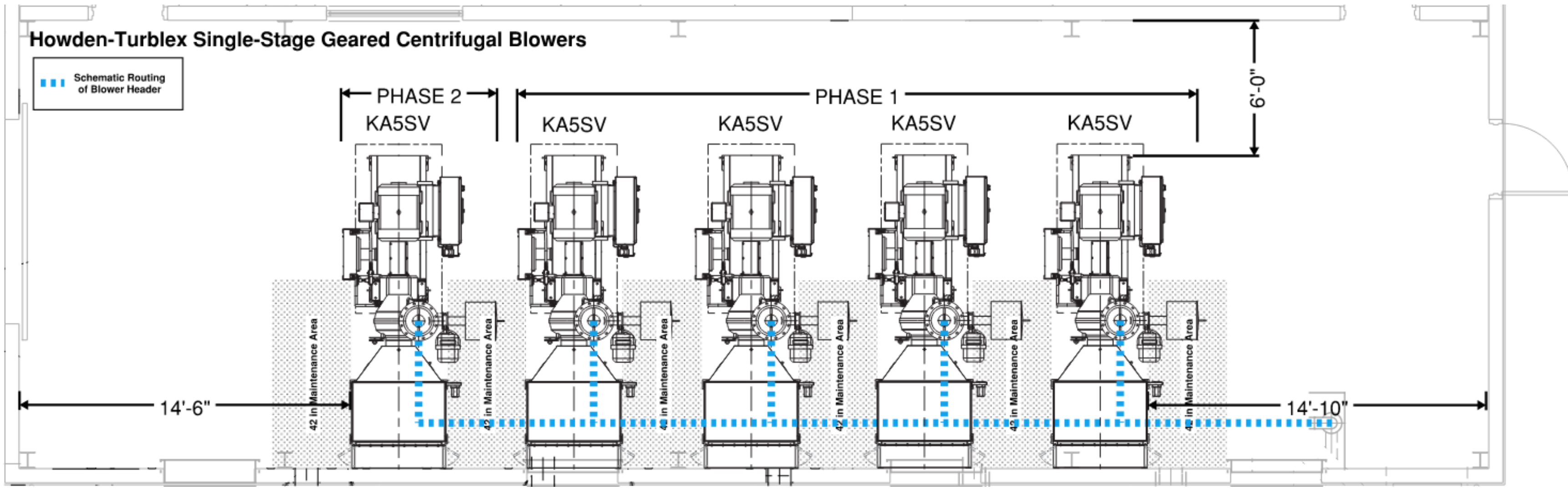

Figure 12.24 Single Stage Geared Centrifugal Blower Alternative Blower Room Plan

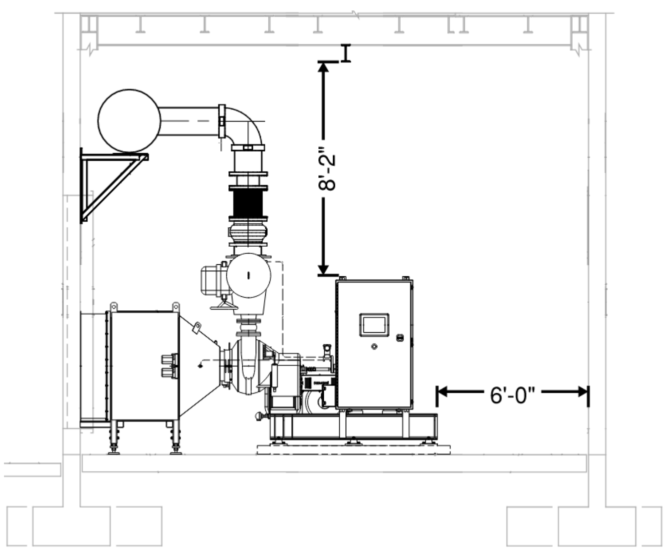

Figure 12.25 Single Stage Geared Centrifugal Blower Alternative Blower Room Section

12.7.2.4 Alternative Comparison

Opinions of probable project costs were developed for each blower alternative and are summarized in Table 12.13 with additional details in Appendix 12B. The capital costs below reflect the costs to increase capacity to reach the 2031/2035 condition (Phase 1) as well as the costs to provide capacity through the planning period (Phase 2). The cost for blower header modifications upstream of the common 30 inch elbow were included for each alternative. As shown in Table 12.13, the expected capital cost ranges for each alternative overlap, meaning they cannot be definitively differentiated by cost at this stage. That said:

- The Howden-Turblex alternative has the highest net present capital cost, which is driven by the blower package cost.
- Blower package costs are similar for the hybrid and high-speed turbo blower alternatives and the resulting Phase 1 project costs are also similar. Blower building heating, ventilation, and air conditioning (HVAC), process integration, and EI&C costs differ due to:
  - Hybrid screw blowers draw air from the cabinet whereas the high-speed turbo blowers have inlet piping that draws air from outside the blower building. The higher blower building HVAC cost for the hybrid screw blower includes additional large openings, louvers, and ventilation fans. For the high-speed turbo blowers, smaller openings are needed but additional stainless piping and inlet filter/silencer assemblies are required.
  - The higher EI&C for the high-speed turbo blower alternatives reflect the master control panel.
- Overall, Phase 1 construction costs are similar for the hybrid screw and high-speed turbo blower alternatives.
- The high-speed turbo blower alternative from APG-Neuros provides sufficient nominal capacity with Phase 1 and therefore has no Phase 2 cost.

Table 12.13 Opinion of Probable Project Cost Summary for Blower Alternatives

Element	Aerzen Hybrid	Aerzen High-Speed Turbo	APG-Neuros High-Speed Turbo(1)	Howden-Turblex Single-Stage Geared Centrifugal(2)
Phase 1				
Demolition	$140,000	$140,000	$140,000	$140,000
Temporary Air Piping	$59,000	$59,000	$59,000	$59,000
Concrete and Finishes	$110,000	$110,000	$110,000	$110,000
Blower Building HVAC	$320,000	$79,000	$110,000	$290,000
Process Integration	$760,000	$910,000	$850,000	$680,000
Blower Package	$1,800,000	$1,800,000	$1,800,000	$2,300,000
EI&C	$1,700,000	$1,900,000	$1,900,000	$1,700,000
Total	**$4,900,000**	**$4,900,000**	**$4,900,000**	**$5,300,000**
Expected Range(3)	**$2.4M to $9.8M**	**$2.5M to $9.8M**	**$2.5M to $9.8M**	**$2.6M to $11M**

Element	Aerzen Hybrid	Aerzen High-Speed Turbo	APG-Neuros High-Speed Turbo(1)	Howden-Turblex Single-Stage Geared Centrifugal(2)
Phase 2				
Demolition	$0	$0	$0	$0
Temporary Air Piping	$0	$0	$0	$0
Concrete and Finishes	$11,000	$11,000	$0	$10,000
Blower Building HVAC	$72,000	$47,000	$0	$100,000
Process Integration	$170,000	$210,000	$0	$150,000
Blower Package	$480,000	$540,000	$0	$620,000
EI&C	$390,000	$390,000	$0	$390,000
Total	**$1,100,000**	**$1,200,000**	**$0**	**$1,300,000**
Expected Range(3)	**$0.56M to $2.2M**	**$0.60M to $2.4M**	**$0M to $0M**	**$0.64M to $2.5M**
Net Present Cost				
Phase 1	$4,700,000	$4,700,000	$4,700,000	$5,100,000
Phase 2	$970,000	$1,000,000	$0	$1,100,000
Total Net Present Cost	**$5,700,000**	**$5,800,000**	**$4,700,000**	**$6,200,000**
Expected Range(3)	**$2.8M to $11M**	**$2.9M to $12M**	**$2.4M to $9.5M**	**$3.1M to $12M**

Notes:
(1) No expansion required for Phase 2 with the APG-Neuros High-Speed Turbo alternative.
(2) Howden provided a range for the blower package cost. The capital cost in this table reflects the minimum of that range.
(3) Class 5 costs per American Association of Cost Engineers have an expected accuracy range of -50 % to +100 %.

A life cycle analysis was completed to compare the net present cost of the four blower alternatives including operating costs over the 25-year planning period. The results of this comparison are summarized in Table 12.14 with additional details provided in Appendix 12B. The operating life cycle costs (electricity and maintenance) range from $1.7M for the single-stage geared centrifugal alternative to $2.1M for the Aerzen high-speed turbo alternative. These are lower than the accuracy range for the capital costs ($7M to $9M), so the alternatives cannot be differentiated based on life cycle costs at this stage. That said:

- The single stage geared centrifugal blowers have the lowest electricity cost among the alternatives. Even with the assumed wire-to-air efficiency, the lower electricity cost is not sufficient to offset the higher capital cost for this alternative.
- Maintenance costs are the highest for the high-speed turbo blowers for the following reasons:
  - These alternatives have more rigorous default filter maintenance schedules than the hybrid and single stage geared centrifugal blower costs.
  - High speed turbo blowers have more electrical components than the other two technologies considered, requiring more frequent replacement.
- Taken together, the APG-Neuros high-speed turbo blower alternative has the lowest net present cost of the alternatives considered by 12 percent to 16 percent.

Table 12.14 Blower Life Cycle Cost Comparison

25-Year Life Cycle Cost	Aerzen Hybrid	Aerzen High-Speed Turbo	APG-Neuros High-Speed Turbo	Howden-Turblex Single-Stage Geared Centrifugal
Capital	$5,700,000	$5,800,000	$4,700,000	$6,200,000
Electricity	$1,600,000	$1,500,000	$1,400,000	$1,300,000
Maintenance	$360,000	$630,000	$600,000	$380,000
Total	**$7,600,000**	**$7,900,000**	**$6,800,000**	**$7,900,000**
Relative Difference(2)	12 percent	16 percent	0 percent	16 percent

Notes:
(1) Howden provided a range for the blower package cost. The capital cost in this table reflects the minimum of that range.
(2) Total 25-year life cycle cost difference relative to the lowest total cost alternative.

In summary, it is recommended that high speed turbo and single-stage geared centrifugal blowers be carried forward into predesign for the following reasons:

- Hybrid rotary screw blowers are not currently available that can deliver the air flow rate for the design conditions while fitting in the existing blower building. The capital and net present cost for these blowers is comparable to the Aerzen high-speed turbo alternative.
- High-speed turbo blowers present the lowest capital and life cycle cost of the three. The range for the two alternatives reflect different assumptions made by the two manufacturers as part of their conceptual design. Multiple manufactures should be considered in predesign with additional coordination such that the resulting blower configurations are directly comparable.
- Single-stage geared centrifugal blowers offer life cycle cost advantages over high-speed turbo blowers. Multiple manufactures should be considered as part of predesign with coordination to ensure that blower configurations are comparable.

12.8 Capital Cost

The conceptual design presented above was used to develop the planning level opinions of probable cost for the first phase expansion. The planning-level costs for phase 1 are summarized in Table 12.15. These costs are based on the Howden-Turblex single-stage geared centrifugal blower alternative and Alternative 2 for air distribution system modifications, which represents the highest cost combination of recommended alternatives. The expected project cost range for the APG-Neuros high-speed turbo blower alternative and Alternative 3 for the air distribution system modifications is $3.8M to $15M.

Table 12.15 Phase 1 Aeration System Expansion Planning Level Cost

Project Element	Total Cost		
	Direct	Construction(1)	Project(2)
Blower Improvements (Howden-Turblex Single-Stage Geared Centrifugal)	**$2,700,000**	**$4,400,000**	**$5,300,000**
Demolition	$70,000	$100,000	$100,000
Temporary Air Piping	$30,000	$50,000	$60,000
Concrete and Finishes	$50,000	$90,000	$100,000

Project Element	Total Cost		
	Direct	Construction(1)	Project(2)
Blower Building HVAC	$100,000	$200,000	$300,000
Process Integration	$300,000	$600,000	$700,000
Blower Package	$1,200,000	$1,900,000	$2,300,000
EI&C	$900,000	$1,400,000	$1,700,000
Air Distribution Piping Modifications (Alternative 2)	**$1,300,000**	**$2,200,000**	**$2,600,000**
Demolition of existing air piping	$30,000	$50,000	$60,000
Temporary air piping	$5,000	$8,000	$10,000
Trenching and earthwork	$400,000	$600,000	$700,000
Process Interconnections	$700,000	$1,200,000	$1,400,000
EI&C	$200,000	$400,000	$400,000
Diffuser Improvements	**$100,000**	**$200,000**	**$200,000**
Remove laterals in Zones 4 and 5	$30,000	$40,000	$50,000
New membrane and lateral installation	$90,000	$200,000	$200,000
Total Cost	**$4,100,000**	**$6,800,000**	**$8,100,000**
Expected Range(3)	**$2.1M to $8.2M**	**$3.4M to $14M**	**$4.1M to $16M**

Notes:
(1) Construction costs include 30 percent estimating contingency, 10% markup for general conditions, and 12% markup for contractor overhead and profit.
(2) Project costs include a 20% markup for total construction costs for engineering, legal, and administrative fees.
(3) Class 5 costs per American Association of Cost Engineers have an expected accuracy range of -50 % to +100 %.

12.9 Conclusions and Recommendations

The existing aeration system at the Forest Grove WRRF was evaluated under the projected flows and loads and proposed operational changes described in the Forest Grove WRRF Capacity Assessment.[10] This evaluation found that the existing aeration system will not be able to satisfy peak process oxygen requirements once the proposed operational changes proposed are implemented. The existing aeration system was found to be deficient as follows:

- There are insufficient diffusers in Zone 5 to transfer the oxygen required to satisfy the projected process oxygen demand under peak conditions without exceeding the manufacturer's recommended maximum air flow rate per diffuser.
- The air flow rate projections are higher than the existing air distribution piping was designed for. These higher air flow rates will cause high velocity and head loss through the existing air distribution piping.
- The existing blowers will not be able to deliver the required projected peak air flow rates at the projected blower discharge pressures.

[10] Carollo Engineers, Inc. (October 2024). TM 10 - Forest Grove WRRF Capacity Assessment, West Basin Facility Plan Project 7054.

Given these deficiencies, modifications to the diffusers, air distribution piping, and blowers were developed to provide capacity through the end of the planning period. Improvements were split into two phases. The first phase would be completed immediately to allow the aeration system to accommodate the higher loads attending the operational changes outlined in the Forest Grove WRRF Capacity Assessment. The second phase would occur as part of the secondary treatment capacity expansion project and would provide aeration system capacity through the planning period (the 2045/2049 condition). Improvements to the existing aeration system were developed to provide sufficient capacity until secondary treatment capacity is reached (the 2031/2035 condition) and not require modification in the second phase (i.e., the expanded system would be able to meet the 2045/2049 condition). The recommended modifications include:

- For the existing diffusers, improvements would occur as part of the first phase with subsequent aeration basins having the same diffuser complement and arrangement as the improved basins.
  - Eight laterals and 208 diffusers would be removed from Zone 4 to improve access.
  - The remaining 468 membranes in Zone 4 would be replaced.
  - An additional 160 diffusers would be installed into Zone 5. The existing diffuser grid would be modified to accommodate the four additional laterals needed for the diffusers and maintain accessibility.
  - The air distribution manifolds in Zones 5 and 6 would be upsized as recommended by the manufacturer to accommodate the higher projected air flowrates.
- For the air distribution piping, three alternatives were developed that reflect different degrees of expansion.
  - Alternative 1 follows the current air distribution approach with one main line supplying air from the blowers to the aeration basins with the lateral feeding each zone branching of the main line. To satisfy maximum recommended velocities at the 2045/2049 condition, all existing air distribution piping would need to be replaced.
  - Alternative 2 would install a new air distribution line to service Aeration Basin 1 and the future Aeration Basin 3. The existing 14 inch main air distribution line would be retained for Aeration Basin 2. The existing air distribution manifold serving Aeration Basin 1 would also be upsized.
  - Alternative 3 retains the existing 14 inch main air distribution line and upsizes the existing air distribution manifold diameter for Aeration Basins 1 and 2.
  - Alternatives 2 and 3 were recommended to be carried forward to predesign for the following reasons:
    - Alternatives 2 and 3 had comparable capital costs that were lower than Alternative 1.
    - Construction sequencing is expected to be easier with Alternatives 2 and 3 than Alternative 1.
- For the blowers, available blower technologies were first screened to identify those most suitable for the present application. Based on the technology screening, hybrid rotary, high-speed turbo, and single stage geared centrifugal were further developed as alternatives.
  - Hybrid rotary screw blowers were more expensive than high-speed turbo blowers and would not fit in the existing blower building.
  - One of the high-speed turbo blower alternatives had the lowest capital and overall net present value of the blower technologies considered.
  - The single stage geared centrifugal blower alternative had the highest capital and lowest operating costs of the alternatives.
  - High-speed turbo and single stage geared centrifugal blowers were recommended to be carried forward to predesign.

12.9.1 Recommendations to Support Preliminary Design

The air flow rate projections are based on process models developed as part of the West Basin Facility Plan project. These models were calibrated and validated to historical operation, which will differ from the proposed future operation. The following are recommended to reduce uncertainty in the model predictions and aeration system requirements:

- Improve the process model fit under peak air flow conditions. This may be achieved with a focused sampling campaign completed when the industrial loads are high. This campaign would target:
  - Improving the wastewater characterization through direct measurement of particulate, filtered, and filtered and flocculated chemical oxygen demand fractions.
  - Refining estimates of future primary clarifier performance with simultaneous bench top settling tests of influent and settled and degritted sewage from the Hillsboro WRRF.
- Refine the air flow rate projections. The air flow rate projections developed herein were approximate based on the objectives of this analysis, process model uncertainty, and process data limitations. The following would help to improve the air flow rate projections for preliminary design:
  - Refine the estimated maximum air flow rate directed to the post-aeration channel. The maximum design value was assumed herein. However, the District generally operates these diffusers with a partially closed valve when online so a lower typical flow rate would be expected.
  - Reinstall the recalibrated air mass flow meters into the aeration basin drop legs. As noted above, the air flow meters on the aeration basin drop legs were inaccurate. The recalibrated AB1 drop leg flow meters were reinstalled in May 2024 and the AB2 drop leg flow meters are expected to be sent out for recalibration in 2025.
  - Update air flow rate projections to include more recent process data. A preliminary comparison of air flow rates measured in 2024 with the recalibrated AB1 drop leg flow meters suggest higher sustained air flow rates, particularly during the summer, than in the data used for the present evaluation (2019 through 2021).
  - Conduct off-gas testing to improve the estimate for oxygen transfer efficiency factor (α)·diffuser fouling factor (F). An empirical model was applied herein to estimate the impacts of process conditions and fouling on the oxygen transfer coefficient. The combined contribution may be measured directly with off-gas testing. This may provide the following potential benefits:
    - The measured α·F may be interpreted directly to infer the relative magnitude of α and F in each zone by comparing the results between zones and with other facilities.
    - As noted above, the empirical α·F model did not indicate that the diffusers in Zone 4 are abnormally fouled. Nevertheless, the historical total air flow rate used to develop the air flow projections may be biased high due to membrane fouling in this zone.
  - Refine the air flow rate peaking factors with dynamic process modeling. The approach adopted herein estimated the peak air flow rates with air flow rate peaking factors applied to the maximum month modeled steady sate air flow rate. These air flow rate peaking factors depend on the existing aeration system and historical operation, both of which will change with the aeration system improvements and future operational changes at the Forest Grove WRRF. The peak air flow rates predicted with dynamic process modeling will be less susceptible to these dependencies.

12.9.2 Recommendations for Preliminary Design

Several simplifying assumptions were adopted for the current planning level analysis. Preliminary design should validate or refine these assumptions:

- Evaluate alternative diffuser technologies. This analysis determined that 9-inch disc diffusers could be removed from Zone 4 which would improve access. While the diffuser density could be reduced, it is still high (18.9 percent) and it may still be difficult to access some diffusers. Alternative diffuser technologies and form factors may be able to meet the oxygen transfer requirements while providing sufficient space for in-basin maintenance activities.
- Explore other options to leverage existing infrastructure in modifying the air distribution piping. Two of the three air distribution piping alternatives evaluated herein were developed to leverage portions of the existing air distribution piping. These may not represent the most efficient air distribution piping configurations or routing for new air distribution yard piping.
- Develop an Applied Flow Technology (AFT) Arrow model of the air distribution system. Air distribution piping pressure losses and velocities as well as the blower header pressures were estimated with empirical head loss relationships. Given the complexity of the system, it is recommended that an AFT Arrow model of the air distribution system be developed to refine these estimates. This would be particularly important if air distribution piping alternatives 2 or 3 are pursued given the elevated velocities and head losses predicted by the empirical models under peak conditions.
- Refine the alternatives to account for secondary treatment requirements beyond the current planning period. A fourth aeration basin will be required after the end of the current planning period but before buildout. Potential limitations in the air distribution piping and diffusers past the planning period should be acknowledged and accommodated into the design at the direction of the District.
- Verify that the existing electrical service will be sufficient to supply the blowers. Historically, the main control centers served a combined 1000 hp in blower motor. The total power draw at the 2045/2049 condition is projected to be up to 1050 hp with all units in service.
- Evaluate having a separate dedicated blower for the aeration channel downstream of secondary clarifiers 1 and 2. The present analysis adopted the historical approach of having a common header to supply air to the aeration basins and the aeration channel downstream of secondary clarifiers 1 and 2. The static pressure is significantly lower in the aeration channel than the aeration basins, as are the diffuser pressure losses. This requires burning head when the air is being supplied to the aeration channel and complicates overall aeration control. An alternative would be to split the header and have a smaller, dedicated blower for the aeration channel downstream of secondary clarifiers 1 and 2 that could operate independent of the aeration basins.
- Evaluate the construction of a new, relocated blower building. The present evaluation assumed the existing blower building would be repurposed. Future secondary treatment capacity will be constructed to the east of the existing aeration basins, further away from the existing blower building. Relocating the blower building to a location central to secondary treatment may reduce air distribution piping lengths and headloss.

APPENDIX 12A

HISTORICAL DATA, ANALYSIS APPROACH, AND DESIGN CRITERIA

HISTORICAL DATA, ANALYSIS APPROACH, AND DESIGN CRITERIA

This appendix details the historical process data analysis that was completed to support the process performance assumptions adopted in the tertiary expansion evaluation.

Historical Air Flow Rate Analysis

Historical data from 2019 through 2021 were analyzed to estimate the total air flow rate delivered to the aeration basins. This total air flow rate was used to estimate air flow rate peaking factors and validate the oxygen transfer efficiency factor (α) and fouling factor (F) model based on the process model calibration and validation developed previously. These historical data included:

- Air flow rate measured by each of the drop leg flow meters for the individual aerated zones of the aeration basins. Clean Water Services (the District) determined that these flow meters were not calibrated.
- Air flow rate measured by the blower header flow meter. This flow meter was installed in 2018 as part of the District's efforts to investigate discrepancies in air flow rate measurements.
- Dissolved oxygen (DO) concentration measured in each of the individual aerated zones of the aeration basins. The District rigorously maintains these instruments and considers the data reliable.

The total air flow rate delivered to the aeration basins that was used to develop peaking factors and validate the α·F model was estimated as follows:

- The sum of the drop leg air flow rates was found to be generally lower than the flow rate measured by the blower header flow meter. This is consistent with the District's earlier finding that the drop leg flow meters were registering inaccurate flow rates.
- Air flow rates measured by the blower header flow meter were truncated at approximately 3500 standard cubic foot per minute (scfm) from 2019 through August of 2021. Thereafter, the maximum registered air flow rate was higher at approximately 4200 scfm. The District indicated that this value was also truncated. This is shown in the plot of the measured header flow rate in Figure 12A.1. The truncation was attributed to a range mismatch in the processing of the flow meter's output.
- The total air flow rate delivered to the aeration basins was estimated from the sum of the drop leg air flow rates by fitting a linear relationship between this and the air flow rate measured by the blower header flow meter for periods when the output from the blower header flow meter was not truncated. This fitted relationship was found to be generally consistent with the relationship fitted by the District as part of their earlier investigation into air flow rate discrepancies.
- Figure 12A.1 depicts the resulting modeled air flow rate to the aeration basins as well as the air flow rate measured by the blower header flow meter. As shown, the modeled air flow rate is consistent with the air flow rate measured by the blower header flow meter when the blower header flow meter output was not truncated. The modeled air flow rate to the aeration basins exceeds the firm capacity

of the existing blowers, which is consistent with the District's experience of needing to operate with all blowers in service under peak air demands. The total air flow rate would be higher with post aeration.

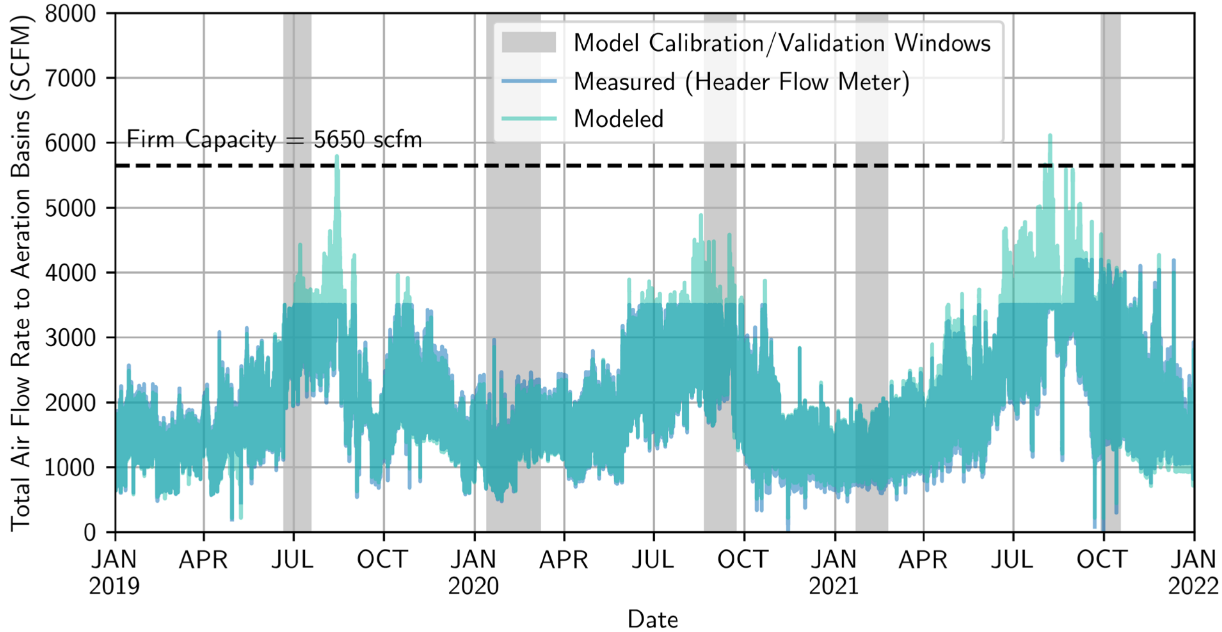

Figure 12A.1 Comparison of Measured and Modeled Header Flow Rate

Air Flow Rate Peaking Factors

The air flow rate peaking factors determined with the modeled total air flow rate to the aeration basins are summarized in Table 12A.1. The extreme peaking factors (set in **bold**) were used in determining the air flow rate projections. The following observations were made for the historical peak air flow rates and peaking factors:

- Peak air flow rates have consistently occurred in August and September and coincide with the increased load from industrial and agricultural contributors.
- Historical peak air flow rates were internally consistent for 2019 and 2021. The peak hour air flow rate typically occurs in the day corresponding to the maximum day air flow rate. The maximum day air flow rate typically occurs in the week corresponding to the maximum week air flow rate. And the maximum week air flow rate typically occurs in the month corresponding to the maximum month air flow rate.

Table 12A.1 Historical Air Flow Rate Peaking Factor Summary

Year	Avg	Min Day			Max Month		Max Week			Max Day			Peak Hour		
	Q_{air} (scfm)	Q_{air} (scfm)	Date	PF[1,2]	Q_{air} (scfm)	Date	Q_{air} (scfm)	Date	PF[1,2]	Q_{air} (scfm)	Date	PF[1]	Q_{air} (scfm)	Date	PF[1,2]
Dry Weather															
2019	2496	1277	09-18	0.512	3549	08-17	4251	08-17	1.198	4936	08-14	1.391	5765	08-14	1.624
2020	2471	1426	05-06	0.577	3002	08-20	3246	09-18	1.081	3622	09-16	1.207	4635	08-17	1.544
2021	2985	1559	05-31	0.522	3935	08-30	4678	08-09	1.189	5026	08-07	1.277	5671	08-07	1.441
Min				**0.512**					1.081			1.207			1.441
Max				0.577					**1.198**			**1.391**			**1.624**
Avg				0.537					1.156			1.292			1.536
Wet Weather															
2019	1477	923	02-13	0.625	1649	02-11	1811	04-29	1.098	1894	04-25	1.149	2969	04-16	1.800
2020	1559	1085	01-29	0.696	1751	03-13	1875	04-30	1.071	2060	04-30	1.176	2740	04-30	1.565
2021	1554	1015	01-13	0.653	1955	04-30	2484	04-28	1.270	2719	04-24	1.391	3476	04-26	1.778
Min				**0.625**					1.071			1.149			1.565
Max				0.696					**1.270**			**1.391**			**1.800**
Avg				0.658					1.146			1.239			1.714

Notes:
(1) Minimum day peaking factor is relative to the average annual air flow rate. Peaking factors for maximum week, maximum day, and peak hour are relative to the maximum month air flow rate.
(2) Values set in **bold** were used for determining air flow rate projections.
Avg - arithmetic average; Max - maximum; Min - minimum; PF - peaking factor; Q_{air} - air flow rate.

Oxygen Transfer Efficiency and Fouling Factor

The oxygen transfer efficiency factor (α) and the diffuser fouling factor (F) are significant parameters in the relationship between the air flow rate and oxygen transfer rate. These factors are difficult to estimate separately for fine bubble diffusers. Therefore, the product α·F is used to represent the combined contributions of wastewater and diffuser fouling on reducing the oxygen transfer efficiency. Off gas testing has not been conducted to measure α·F directly. Therefore, an empirical relationship relating α·F to the mixed liquor suspended solids (MLSS) concentration and the solids retention time (SRT) was used to estimate α·F for the determination of air flow rate projections.

The empirical α·F relationship was evaluated against the air flow rates measured for the model calibration and validation windows. The relative performance of the empirical relationship was evaluated in terms of the measured versus modeled air flow rate (depicted in Figure 12A.2). Two comparisons were completed. In the first (Figure 12.2A), the air flow rate in each aerated zone was compared. This analysis apportioned the total air flow rate estimated with the extrapolated dataset based on the measured header air flow rate. In the second comparison (Figure 2B), the total air flow rate was compared. The following observations were made:

- On an individual zone air flow rate basis (Figure 12A.2A), the empirical model predicts air flow rates that are generally within 20 percent of the measured air flow rate. Modeled air flow rates tend to exceed the measured air flow rate under lower air flow rates.
- On a total air flow rate basis (Figure 12A.2B), the empirical model generally results in air flow rates that are consistent with or greater than the corresponding measured air flow rates.
- On both bases, the modeled air flow rates for the dry weather validation window are significantly lower than measured. This may be attributed to the suboptimal fit of the process model to the historical data during that period. These data were excluded from the present analysis.

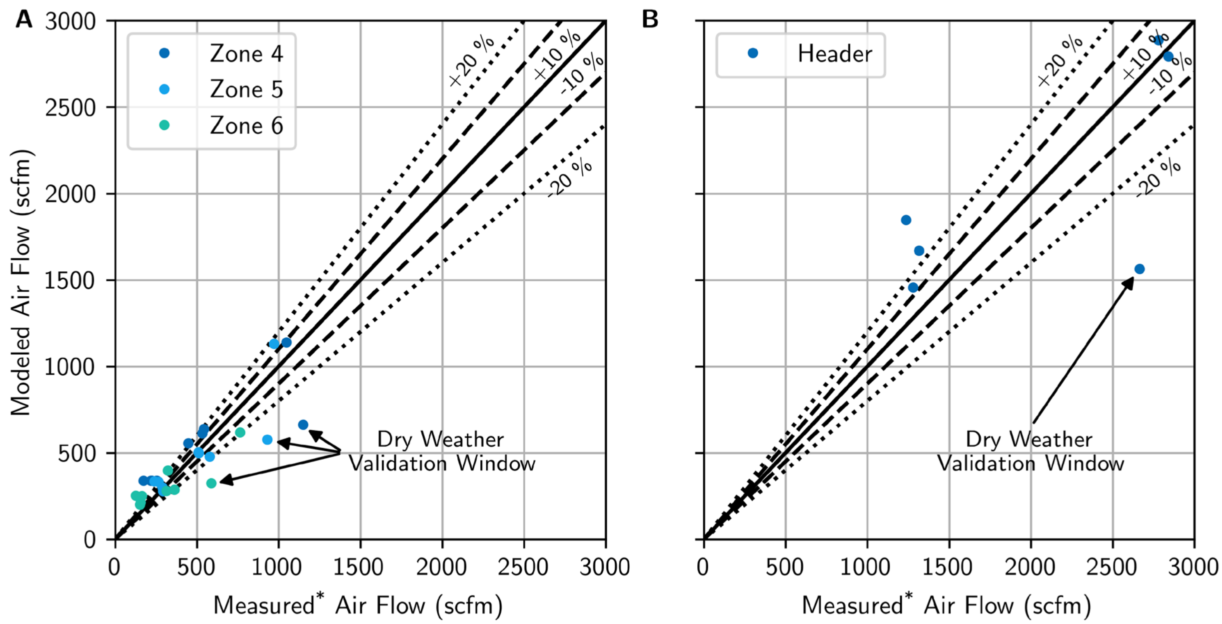

Figure 12A.2 Modeled Versus Measured* Air Flow Rates

Notes: Modeled air flow rate is the air flow rate calculated from the oxygen demand determined from the calibrated process model using the empirical α·F relationship. The Measured air flow rate is the air flow rate estimated from the measured air flow rates that have been extrapolated with the fitted linear relationship to impute truncated values. Panel A depicts the air flow rates in the individual zones while panel B depicts the total air flow rate.*

The empirical α·F was adopted to determine air flow rate projections since the objective of the present analysis is to predict the total air flow rate and the empirical α·F model was reasonably conservative on this basis.

Air Flow Rate Projection and Analysis Approach

Air flow rate projections were estimated using the models developed for the Forest Grove Capacity Assessment.[1] These models were developed with the following assumptions:

- The two new primary clarifiers currently under construction are operational.
- The Council Creek pump station is online.
- Primary solids, waste activated sludge, and transfer flows are conveyed to the Rock Creek Water Resource Recovery Facility (WRRF) for treatment. A minimum transfer flow of 1 million gallons per day (mgd) was assumed for all conditions.
- Peak flows up to 30 mgd will be treated through secondary treatment during the wet weather season.
- Influent flows exceeding 12 mgd during the dry weather season will be transferred to the Rock Creek WRRF via the flow transfer system (limited by the natural treatment system).

[1] Carollo Engineers, Inc. (October 2024). TM 10 - Forest Grove WRRF Capacity Assessment, West Basin Facility Plan Project 7054.

- Aeration basins are operated to achieve full nitrification in the dry weather season and partial nitrification in the wet weather season.
- Aeration basins are operated in anaerobic/oxic (AO) mode.
- All aeration basins are in service.
- A dissolved oxygen concentration of 2 mg/L is maintained in each aerated zone.

Models were developed in the Forest Grove Capacity Assessment for four flow and load conditions:

- Modified average dry weather (ADW*). This condition was developed to account for the significant industrial contribution in the Forest Grove collection system in late summer which skewed the projected average dry weather load. This condition used the average wet weather 5 day carbonaceous biochemical oxygen demand and total suspended solids load projections and the average dry weather flow projection.
- Average wet weather (AWW).
- Maximum month dry weather (MMDW).
- Maximum month wet weather (MMWW). These models were evaluated, but not included in the present analysis. As noted above, peak air flow demands have consistently occurred in the dry weather season. Therefore, it was assumed for the present analysis that dry weather would continue to be the limiting condition for aeration capacity.

As noted in *TM 10 - Forest Grove WRRF Capacity Assessment*, the influent loads have been relatively stable in the four years since the flow and load projections were developed. The trigger years developed for secondary treatment therein were therefore expressed as a range. The earlier year in the range was from the unmodified flow and load projections and the later year was determined by shifting the influent loads by four years. For the present analysis, air flow rates were projected for three time points:

- Current conditions (2020/2024).
- Existing secondary treatment at capacity (2031/2035).
- End of the current planning period (2045/2049). Air flow rates were developed for this condition assuming a third aeration basin identical to Aeration Basins 1 and 2 will be constructed to expand secondary treatment capacity.

Air flow rates were determined for each condition to satisfy the modeled steady state field oxygen transfer rate in each aerated zone based on the following assumptions:

- The empirical $\alpha \cdot F$ model described above was used to estimate the impact of wastewater and diffuser fouling on the oxygen transfer rate.
- The standard oxygen transfer efficiency was determined using regression relationships fitted to diffuser manufacture data.
- The aeration basin diffuser submergence is 18.7 feet, which is the value specified in the original manufacturer's submittal. The corresponds to a side water depth of 19.7 feet.
- The post-aeration diffuser submergence is 6.6 feet. This corresponds to the water surface elevation for the average wet weather design flow condition (5.8 mgd) from the Forest Grove Liquid Stream Upgrade Project hydraulic profile.

The peaking factors determined from the historical air flow rate analysis (Table 12A.1) were applied to the individual zone air flow rates determined from the ADW*, AWW, MMDW, and MMWW models to estimate the minimum day, average, maximum month, maximum week, maximum day, and peak hour zone air flow rates. Table 12A.2 summarizes the peaking factors and models used to estimate each zone air flow rate.

Table 12A.2 Air Flow Rate Determination Summary

Air Flow Rate Condition(1)	Air Flow Rate Peaking Factor(1)	Basis Model Condition for Air Flow Rate Peaking Factor(1)	Basis Model Condition Secondary Treatment Performance and Operation	Wastewater Temperature (°C)	Post-Aeration Air Flow Rate (scfm)
Minimum Day (DW)	0.436	ADW*	▪ Complete nitrification ▪ aSRT = 6.2 d	16.2	0
Minimum Day (WW)	0.436	AWW	▪ Partial nitrification ▪ aSRT = 4.9 d	11.5	640
Average (DW)	1.0	ADW*	▪ Complete nitrification ▪ aSRT = 6.2 d	16.2	0
Average (WW)	1.0	AWW	▪ Partial nitrification ▪ aSRT = 4.9 d	11.5	640
Maximum Month (DW)	1.0	MMDW	▪ Complete nitrification ▪ aSRT = 4.5 d	18.9	640
Maximum Week (DW)	1.198	MMDW	▪ Complete nitrification ▪ aSRT = 4.5 d	18.9	640
Maximum Day (DW)	1.391	MMDW	▪ Complete nitrification ▪ aSRT = 4.5 d	18.9	640
Peak Hour (DW)	1.624	MMDW	▪ Complete nitrification ▪ aSRT = 4.5 d	18.9	640

Notes:
(1) The air flow rate was determined by multiplying the air flow rate peaking factor by the air flow rate estimated for the model of the flow and load condition developed as part of the Forest Grove Capacity Assessment.
°C - degree Celsius; aSRT - aerobic solids retention time; d - day; DW - dry weather; WW - wet weather.

The aeration basin total air flow rate was determined as the sum of the individual zone air flow rates. The blower total air flow rate was determined as the sum of the aeration basin total air flow rate and the air flow rate directed to the post aeration basin. As shown in Table 12A.2, it was assumed that air would be directed to the post-aeration diffusers under the average wet weather condition as well as the peak dry weather conditions. As noted above, the post-aeration diffusers are only used when discharging directly to the outfall, which typically occurs in the wet weather and shoulder seasons. The industrial contribution that drives the peak dry weather loads may extend into the fall shoulder season. As such, it was conservatively assumed that the air would be directed to the post-aeration diffusers under peak conditions.

The blower discharge pressure was estimated for each condition as follows:

- The pressure at the top of each drop leg was determined as the sum of the estimated pressure drop across the diffusers in the grid and the static pressure due to diffuser submergence.

- The pressure drop across each control valve for each zone was estimated iteratively to balance the pressure at common nodes.
- The blower discharge pressure was then estimated based on the smooth pipe head loss in the air distribution piping. A minimum air distribution system head loss between the maximum top-of-drop-leg pressure and the blower discharge of 1 pounds per square inch (psi) was adopted to maintain conservatism in the blower selection.

The delivered, motor, and wire power estimates for each condition were developed from the following:

- A head loss of 0.3 psi through the blower inlet.
- Motor efficiency of 95 percent.
- VFD efficiency of 98 percent.
- Ambient air conditions were determined from historical data from the Hillsboro-Portland Airport (KHIO) from 1998 through 2023.[2] Average wet and dry weather ambient conditions were calculated as the mean of the data during the respective season. Maximum month, maximum week, maximum day, and peak hour conditions were determined as the empirical quantile from the data subset in the respective season with probabilities of 83.33 percent, 96.17 percent, 99.45 percent, and 99.98 percent, respectively. Average conditions were used for minimum day conditions. The results are summarized in Table 12A.3.

Table 12A.3 Ambient Air Conditions

Conditions	Probability(1) (%)	Temperature (°C)	Absolute Pressure(2) (psi)	Relative Humidity (%)
Average (WW)	n/a	5.93	14.63	85.82
Minimum Day (WW)	n/a	5.93	14.63	85.82
Maximum Month (WW)	83.33	16.66	14.60	68.92
Average (DW)	n/a	15.52	14.61	72.09
Minimum Day (DW)	n/a	15.52	14.61	72.09
Maximum Month (DW)	83.33	26.45	14.58	42.39
Maximum Week (DW)	96.17	31.73	14.55	32.61
Maximum Day (DW)	99.45	36.05	14.52	27.39
Peak Hour (DW)	99.98	42.20	14.58	24.13

Notes:
(1) Probability threshold within the seasonal data subset.
(2) Absolute atmospheric pressure estimated based on the site elevation of 208 feet above mean sea level. Seasonal pressure scaled to station pressure measured at the Hillsboro-Portland Airport (KHIO).

[2] Data accessed 2024-08-09 from weather.com.

Aeration System Design Criteria

Diffuser and blower performance was evaluated based on the following design criteria:

- The air flow rates per diffuser were limited to the following minimum and maximum values. These values are based on EDI's guidance for and Carollo's experience with 9 inch diameter FlexAir MicroPore membrane disc diffusers with 0.25 inch diameter flow control orifices.
  - » The minimum allowable air flow rate per diffuser of 0.6 scfm was adopted for all conditions to provide even air flow distribution throughout the grid.
  - » The maximum preferred air flow rate per diffuser of 3 scfm was adopted for minimum and average conditions.
  - » The maximum allowable air flow rate per diffuser of 4 scfm was adopted for maximum month, maximum week, maximum day, and peak hour conditions.
- A minimum air flow rate of 0.12 scfm per square feet was assumed for each grid to provide sufficient mixing.
- Firm blower capacity defined by the largest unit out of service was assumed for all conditions.
- A maximum blower discharge pressure of 10.1 psi. Typically, at least 80 percent of the blower discharge pressure should be due to static pressure and the total frictional and minor head losses should amount to no more than 2 psi. The 10.1 psi is generally consistent with the current rated discharge pressure of the Aerzen blowers (10 psi). Higher discharge pressures may be possible with new blowers.
- The air velocities under peak air flow rate conditions was limited to the following maximum values for air distribution piping outside measurement and control sections.[3] These velocity targets are preferred to balance air distribution piping head loss and noise generation.
  - » 3000 foot per minute (fpm) in pipes with nominal diameters between 4 inches and 10 inches.
  - » 4000 fpm in pipes with nominal diameters between 12 inches and 24 inches.

[3] Metcalf and Eddy (2014). Wastewater Engineering: Treatment and Resource Recovery. Fifth Edition.

APPENDIX 12B

LIFE CYCLE AND OPINION OF PROBABLE COSTS

LIFE CYCLE AND OPINION OF PROBABLE COSTS

All cost estimates are Class 5, order-of-magnitude estimates as defined by the American Association of Cost Engineers (AACE). A Class 5 estimate is one that is made without detailed engineering data and uses techniques such as cost curves and scaling factors applied to similar projects. The overall expected level of accuracy of the cost estimates presented is -20 to -50 percent on the low end and + 30 to +100 percent on the high end. This means that bids can be expected to fall within a range of 50 percent under to 100 percent over the estimate for each project. This is consistent with the guidelines established by the AACE for planning level studies.

Cost estimates were developed with the following approach:

- January 2024 was adopted as the current cost basis.
- Unit pricing developed prior to the current cost basis were escalated based on the Engineering News-Record Construction Cost Index (ENR CCI). The ENR CCI for the current cost basis was 13,515.
- Alternatives were compared on a net present cost basis. For each alternative, capital and operating costs were escalated to the year of occurrence to develop the cost series. These costs were then discounted to the current cost basis for comparison.
- The analysis periods used to develop net present costs from the cost series of each alternative was 2024 through 2049.
- For each alternative, aeration system capacity would be expanded in two phases:
  - The first phase will occur by 2026 and will expand aeration system capacity to provide aeration capacity until the secondary treatment expansion project (the 2031/2035 condition).
  - The second phase will occur by 2031 and will expand the aeration system capacity to provide aeration capacity through the planning period (the 2045/2049 condition).
- Costs common to all alternatives were excluded from the analysis.
- Capital repair and replacement costs were annualized relative to the design life of the component.
- Assumptions adopted to develop costs for all alternatives are summarized in Table 12B.1.

Table 12B.1 Assumptions Adopted for All Alternatives to Develop Probable Costs

Parameter	Value	Notes/Reference
Operating Unit Costs		
Operations and maintenance labor ($/hr)	69.61(1,2)	East Basin Master Plan, Table 1.1, p. 1-3
Power ($/kWh)	0.07(1,2)	East Basin Master Plan, Table 1.1, p. 1-3
Capital Improvement Markups		
Contingency	30%	West Basin Alternatives CAMP
Contractor general conditions	10%	West Basin Alternatives CAMP
Bonds and insurance	2.9%	
Contractor overhead and profit	12%	West Basin Alternatives CAMP
Engineering, legal, and administration	20%	West Basin Alternatives CAMP
Project cost to direct cost ratio ($/$)	2.11	Calculated from markups
Net Present Cost Parameters		
Phase 1 project construction duration	2 years	Used to develop costs series to midpoint of construction.
Phase 2 project construction duration	4 years	Used to develop costs series to midpoint of construction.
Price escalation rate (annual inflation rate)	2% per year	East Basin Master Plan, Table 1.1, p. 1-3;
Discount rate (Interest rate used to determine present value of future cash)	4% per year	East Basin Master Plan, Table 1.1, p. 1-3

Notes:
(1) Expressed on current cost basis (January 2024).
(2) June 2020, ENR CCI of 11436.

Detailed Opinion of Probable Costs for Diffuser Grid Modifications

One alternative was developed for diffuser grid modifications. Diffuser grid modification capital costs were developed for Phase 1 improvements based on a quote from EDI. These are summarized in Table 12B.2. It was assumed that no diffuser modifications in Aeration Basins 1 and 2 would be required for Phase 2 and that new diffusers in Aeration Basin 3 would be the same regardless of air distribution system or blower alternative selection. Likewise, life cycle costs for the diffusers were not considered in any net present cost comparisons as these were assumed to be constant across air distribution system and blower alternatives. As such, diffuser life cycle costs including membrane maintenance and replacement were not developed.

Table 12B.2 Detailed Opinion of Probable Direct Capital Cost for Phase 1 Diffuser Grid Modifications

Item	Unit Cost	Quantity	Total Cost
Diffuser Grid Modifications (200 new diffuser assemblies, 936 membranes, air header and manifold assemblies)			
Demolition of existing diffusers and laterals in Zones 4 and 5	$27,000	1	$27,000
Concrete repair/patching allowance	$5,000	1	$5,000
Diffuser, membrane, air header, and manifold package	$89,000	1	$89,000
Total Direct Cost			**$120,000**
Contingency (30%)			$36,000
Subtotal			$160,000
General conditions (10%)			$16,000
Subtotal			$170,000
Bonds and insurance (2.9%)			$5,000
Subtotal			$180,000
Overhead and profit (12%)			$21,000
Total Construction Cost			**$200,000**
Engineering, legal, and administration (20%)			$40,000
Total Project Cost			**$240,000**

Detailed Opinion of Probable Costs for Air Distribution Piping Alternatives

Three air distribution piping alternatives were developed.

Alternative 1

Table 12B.3 Detailed Opinion of Probable Direct Capital Cost for Air Distribution Piping Alternative 1, Phase 1

Item	Unit Cost	Quantity	Total Cost
Air Distribution Piping Alternative 1, Phase 1			
Temporary air piping	$50,000	1	$50,000
Demolition of existing air distribution piping	$43,000	1	$43,000
Yard piping	$240,000	1	$240,000
Process piping, fittings, and valves	$990,000	1	$990,000
Electrical, instrumentation, and controls	$230,000	1	$230,000
Total Direct Cost			**$1,500,000**
Contingency (30%)			$460,000
Subtotal			$2,000,000
General conditions (10%)			$200,000
Subtotal			$2,200,000
Bonds and insurance (2.9%)			$64,000
Subtotal			$2,300,000
Overhead and profit (12%)			$270,000
Total Construction Cost			**$2,600,000**
Engineering, legal, and administration (20%)			$510,000
Total Project Cost			**$3,100,000**

Table 12B.4 Detailed Opinion of Probable Direct Capital Cost for Air Distribution Piping Alternative 1, Phase 2

Item	Unit Cost	Quantity	Total Cost
Air Distribution Piping Alternative 1, Phase 2			
Temporary air piping	$0	1	$0
Demolition of existing air distribution piping	$0	1	$0
Yard piping	$68,000	1	$68,000
Process piping, fittings, and valves	$390,000	1	$390,000
Electrical, instrumentation, and controls	$110,000	1	$110,000
Total Direct Cost			**$560,000**
Contingency (30%)			$170,000
Subtotal			$730,000
General conditions (10%)			$73,000
Subtotal			$810,000
Bonds and insurance (2.9%)			$23,000
Subtotal			$830,000
Overhead and profit (12%)			$100,000
Total Construction Cost			**$930,000**
Engineering, legal, and administration (20%)			$190,000
Total Project Cost			**$1,100,000**

Alternative 2

Table 12B.5 Detailed Opinion of Probable Direct Capital Cost for Air Distribution Piping Alternative 2, Phase 1

Item	Unit Cost	Quantity	Total Cost
Air Distribution Piping Alternative 2, Phase 1			
Temporary air piping	$5,000	1	$5,000
Demolition of existing air distribution piping	$28,000	1	$28,000
Yard piping	$350,000	1	$350,000
Process piping, fittings, and valves	$700,000	1	$700,000
Electrical, instrumentation, and controls	$230,000	1	$230,000
Total Direct Cost			**$1,300,000**
Contingency (30%)			$400,000
Subtotal			$1,700,000
General conditions (10%)			$170,000
Subtotal			$1,900,000
Bonds and insurance (2.9%)			$55,000
Subtotal			$1,900,000
Overhead and profit (12%)			$230,000
Total Construction Cost			**$2,200,000**
Engineering, legal, and administration (20%)			$430,000
Total Project Cost			**$2,600,000**

Table 12B.6 Detailed Opinion of Probable Direct Capital Cost for Air Distribution Piping Alternative 2, Phase 2

Item	Unit Cost	Quantity	Total Cost
Air Distribution Piping Alternative 2, Phase 2			
Temporary air piping	$0	1	$0
Demolition of existing air distribution piping	$0	1	$0
Yard piping	$43,000	1	$43,000
Process piping, fittings, and valves	$350,000	1	$350,000
Electrical, instrumentation, and controls	$110,000	1	$110,000
Total Direct Cost			**$500,000**
Contingency (30%)			$150,000
Subtotal			$650,000
General conditions (10%)			$65,000
Subtotal			$710,000
Bonds and insurance (2.9%)			$21,000
Subtotal			$730,000
Overhead and profit (12%)			$88,000
Total Construction Cost			**$820,000**
Engineering, legal, and administration (20%)			$160,000
Total Project Cost			**$990,000**

Alternative 3

Table 12B.7 Detailed Opinion of Probable Direct Capital Cost for Air Distribution Piping Alternative 3, Phase 1

Item	Unit Cost	Quantity	Total Cost
Air Distribution Piping Alternative 3, Phase 1			
Temporary air piping	$25,000	1	$25,000
Demolition of existing air distribution piping	$33,000	1	$33,000
Yard piping	$39,000	1	$39,000
Process piping, fittings, and valves	$950,000	1	$950,000
Electrical, instrumentation, and controls	$230,000	1	$230,000
Total Direct Cost			**$1,300,000**
Contingency (30%)			$380,000
Subtotal			$1,700,000
General conditions (10%)			$170,000
Subtotal			$1,800,000
Bonds and insurance (2.9%)			$53,000
Subtotal			$1,900,000
Overhead and profit (12%)			$220,000
Total Construction Cost			**$2,100,000**
Engineering, legal, and administration (20%)			$420,000
Total Project Cost			**$2,500,000**

Table 12B.8 Detailed Opinion of Probable Direct Capital Cost for Air Distribution Piping Alternative 3, Phase 2

Item	Unit Cost	Quantity	Total Cost
Air Distribution Piping Alternative 3, Phase 2			
Temporary air piping	$0	1	$0
Demolition of existing air distribution piping	$0	1	$0
Yard piping	$68,000	1	$68,000
Process piping, fittings, and valves	$410,000	1	$410,000
Electrical, instrumentation, and controls	$110,000	1	$110,000
Total Direct Cost			**$590,000**
Contingency (30%)			$180,000
Subtotal			$770,000
General conditions (10%)			$77,000
Subtotal			$840,000
Bonds and insurance (2.9%)			$24,000
Subtotal			$870,000
Overhead and profit (12%)			$100,000
Total Construction Cost			**$970,000**
Engineering, legal, and administration (20%)			$190,000
Total Project Cost			**$1,200,000**

Detailed Opinion of Probable Costs for Blower Alternatives

Hybrid Rotary Screw Blower Alternative (Aerzen)

Table 12B.9 Detailed Opinion of Probable Direct Capital Cost for the Aerzen Hybrid Rotary Screw Blower Alternative, Phase 1

Item	Unit Cost	Quantity	Total Cost
Hybrid Rotary Screw Blower Alternative, Aerzen, Phase 1			
Temporary air piping	$30,000	1	$30,000
Demolition of existing header and blowers	$69,000	1	$69,000
Concrete and Finishes	$55,000	1	$55,000
Blower building HVAC	$160,000	1	$160,000
Process piping, fittings, and valves	$380,000	1	$380,000
Blower package	$910,000	1	$910,000
Electrical, instrumentation, and controls	$870,000	1	$870,000
Total Direct Cost			**$2,500,000**
Contingency (30%)			$740,000
Subtotal			$3,200,000
General conditions (10%)			$320,000
Subtotal			$3,500,000
Bonds and insurance (2.9%)			$100,000
Subtotal			$3,600,000
Overhead and profit (12%)			$440,000
Total Construction Cost			**$4,100,000**
Engineering, legal, and administration (20%)			$810,000
Total Project Cost			**$4,900,000**

Table 12B.10 Detailed Opinion of Probable Direct Capital Cost for the Aerzen Hybrid Rotary Screw Blower Alternative, Phase 2

Item	Unit Cost	Quantity	Total Cost
Hybrid Rotary Screw Blower Alternative, Aerzen, Phase 2			
Temporary air piping	$0	1	$0
Demolition of existing header and blowers	$0	1	$0
Concrete and Finishes	$5,600	1	$5,600
Blower building HVAC	$37,000	1	$37,000
Process piping, fittings, and valves	$84,000	1	$84,000
Blower package	$240,000	1	$240,000
Electrical, instrumentation, and controls	$200,000	1	$200,000
Total Direct Cost			**$570,000**
Contingency (30%)			$170,000
Subtotal			$740,000
General conditions (10%)			$74,000
Subtotal			$810,000
Bonds and insurance (2.9%)			$23,000
Subtotal			$830,000
Overhead and profit (12%)			$100,000
Total Construction Cost			**$930,000**
Engineering, legal, and administration (20%)			$190,000
Total Project Cost			**$1,100,000**

High-Speed Turbo Blower Alternative (Aerzen)

Table 12B.11 Detailed Opinion of Probable Direct Capital Cost for the Aerzen High Speed Turbo Blower Alternative, Phase 1

Item	Unit Cost	Quantity	Total Cost
High Speed Turbo Blower Alternative, Aerzen, Phase 1			
Temporary air piping	$30,000	1	$30,000
Demolition of existing header and blowers	$69,000	1	$69,000
Concrete and Finishes	$54,000	1	$54,000
Blower building HVAC	$40,000	1	$40,000
Process piping, fittings, and valves	$460,000	1	$460,000
Blower package	$970,000	1	$970,000
Electrical, instrumentation, and controls	$870,000	1	$870,000
Total Direct Cost			**$2,500,000**
Contingency (30%)			$750,000
Subtotal			$3,200,000
General conditions (10%)			$320,000
Subtotal			$3,600,000
Bonds and insurance (2.9%)			$100,000
Subtotal			$3,700,000
Overhead and profit (12%)			$440,000
Total Construction Cost			**$4,100,000**
Engineering, legal, and administration (20%)			$820,000
Total Project Cost			**$4,900,000**

Table 12B.12 Detailed Opinion of Probable Direct Capital Cost for the Aerzen High Speed Turbo Blower Alternative, Phase 2

Item	Unit Cost	Quantity	Total Cost
High Speed Turbo Blower Alternative, Aerzen, Phase 2			
Temporary air piping	$0	1	$0
Demolition of existing header and blowers	$0	1	$0
Concrete and Finishes	$5,500	1	$5,500
Blower building HVAC	$24,000	1	$24,000
Process piping, fittings, and valves	$100,000	1	$100,000
Blower package	$270,000	1	$270,000
Electrical, instrumentation, and controls	$200,000	1	$200,000
Total Direct Cost			**$600,000**
Contingency (30%)			$180,000
Subtotal			$780,000
General conditions (10%)			$78,000
Subtotal			$860,000
Bonds and insurance (2.9%)			$25,000
Subtotal			$890,000
Overhead and profit (12%)			$110,000
Total Construction Cost			**$990,000**
Engineering, legal, and administration (20%)			$200,000
Total Project Cost			**$1,200,000**

High-Speed Turbo Blower Alternative (APG-Neuros)

Phase 1 provides sufficient capacity through the planning period. As such, a second phase to expand capacity after Phase 1 is not needed with this alternative.

Table 12B.13 Detailed Opinion of Probable Direct Capital Cost for the APG-Neuros High Speed Turbo Blower Alternative, Phase 1

Item	Unit Cost	Quantity	Total Cost
High Speed Turbo Blower Alternative, APG-Neuros, Phase 1			
Temporary air piping	$30,000	1	$30,000
Demolition of existing header and blowers	$69,000	1	$69,000
Concrete and Finishes	$54,000	1	$54,000
Blower building HVAC	$54,000	1	$54,000
Process piping, fittings, and valves	$430,000	1	$430,000
Blower package	$990,000	1	$990,000
Electrical, instrumentation, and controls	$870,000	1	$870,000

Item	Unit Cost	Quantity	Total Cost
Total Direct Cost			**$2,500,000**
Contingency (30%)			$750,000
Subtotal			$3,200,000
General conditions (10%)			$320,000
Subtotal			$3,600,000
Bonds and insurance (2.9%)			$100,000
Subtotal			$3,700,000
Overhead and profit (12%)			$440,000
Total Construction Cost			**$4,100,000**
Engineering, legal, and administration (20%)			$820,000
Total Project Cost			**$4,900,000**

Single-Stage Geared Centrifugal Blower Alternative (Howden)

Table 12B.14 Detailed Opinion of Probable Direct Capital Cost for the Howden/Turblex Single-Stage Geared Centrifugal Blower Alternative, Phase 1

Item	Unit Cost	Quantity	Total Cost
Single-Stage Geared Centrifugal Blower Alternative, Howden, Phase 1			
Temporary air piping	$30,000	1	$30,000
Demolition of existing header and blowers	$69,000	1	$69,000
Concrete and Finishes	$53,000	1	$53,000
Blower building HVAC	$150,000	1	$150,000
Process piping, fittings, and valves	$340,000	1	$340,000
Blower package	$1,400,000(1)	1	$1,400,000
Electrical, instrumentation, and controls	$870,000	1	$870,000
Total Direct Cost			**$2,900,000**
Contingency (30%)			$880,000
Subtotal			$3,800,000
General conditions (10%)			$380,000
Subtotal			$4,200,000
Bonds and insurance (2.9%)			$120,000
Subtotal			$4,300,000
Overhead and profit (12%)			$520,000
Total Construction Cost			**$4,800,000**
Engineering, legal, and administration (20%)			$970,000
Total Project Cost			**$5,800,000**

Notes:
(1) Howden provided a range for the blower package cost. The blower package cost in this table reflects the maximum of that range.

Table 12B.15 Detailed Opinion of Probable Direct Capital Cost for the Howden/Turblex Single-Stage Geared Centrifugal Blower Alternative, Phase 2

Item	Unit Cost	Quantity	Total Cost
Single-Stage Geared Centrifugal Blower Alternative, Howden, Phase 2			
Temporary air piping	$0	1	$0
Demolition of existing header and blowers	$0	1	$0
Concrete and Finishes	$5,300	1	$5,300
Blower building HVAC	$51,000	1	$51,000
Process piping, fittings, and valves	$74,000	1	$74,000
Blower package	$380,000(1)	1	$380,000
Electrical, instrumentation, and controls	$200,000	1	$200,000
Total Direct Cost			**$710,000**
Contingency (30%)			$210,000
Subtotal			$920,000
General conditions (10%)			$92,000
Subtotal			$1,000,000
Bonds and insurance (2.9%)			$29,000
Subtotal			$1,000,000
Overhead and profit (12%)			$130,000
Total Construction Cost			**$1,200,000**
Engineering, legal, and administration (20%)			$230,000
Total Project Cost			**$1,400,000**

Notes:
(1) Howden provided a range for the blower package cost. The blower package cost in this table reflects the maximum of that range.