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Ullrich Water Treatment Plant Site Sound Propagation Study

Modeling Report

9 November 2023

Prepared for

Austin Water
City of Austin
625 East 10th Street
Austin, Texas 78701

KJ Project No. 2245006.00
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List of Abbreviations/Symbols

AW	Austin Water
CNEL	Community Noise Equivalent Level
COA	City of Austin
COWLH	City of West Lake Hills
dB	decibel
dBA	A-weighted decibel
Hz	Hertz
L_d	Daytime equivalent A-weighted sound level between the hours of 0700 and 2200
L_{dn}	Day-night average sound level; 24-hour A-weighted equivalent sound level
L_{eq}	Equivalent continuous A-weighted sound level over a given time interval
L_n	Nighttime equivalent A-weighted sound level between the hours of 2200 and 0700
L_{max}	Maximum equivalent A-weighted sound level for a given time interval or event
L_{min}	Minimum equivalent A-weighted sound level for a given time interval or event
MGD	million gallons per day
SMP	Sound Measurement Plan
UWTP	Ullrich Water Treatment Plant
VdB	vibration decibel

Executive Summary

The Ullrich Water Treatment Plant (UWTP), located within the City of Austin (COA), has the capacity to treat 167 million gallons per day (MGD) of water from the Lower Colorado River. In 2022, Austin Water (AW) identified the need to perform a site acoustic study at the UWTP to determine sources of sound and ground vibration at the plant which could affect adjacent properties in West Lake Hills. AW retained Kennedy Jenks and Collaboration in Science and Technology (CSTI) to conduct a noise study of the UWTP.

A sound measurement plan was developed with sound data collected in 2022 from various operational activities at the facility. The results of the study were presented to AW in a letter report titled "*Ullrich Water Treatment Plant Site Sound Propagation Study",* dated 5 May 2023. After the completion of the *Ullrich Water Treatment Plant Site Sound Propagation Study*, AW requested additional support to prepare an acoustic model of the UWTP and to evaluate noise mitigation alternatives.

Certain operations at the UWTP have been identified as being the primary source of unwanted noise which is readily perceptible to nearby neighbors. These sources, which were measured during the *Ullrich Water Treatment Plant Site Sound Propagation Study*, include lime delivery blowers, basin discharge waterfalls, facility operations, running HVAC equipment, truck traffic and the noise associated with the periodic cleaning of the basins by a specialized contractor. However, the cleaning operations and lime blower activities produced the maximum decibel recordings during the sound study, as compared to other operations. These two operating scenarios would benefit most from acoustic treatment. Acoustic treatments for the cleaning of Basin #1 will also mitigate the other operational noise sources, such as waterfalls, that have been identified as an operational noise of concern.

Using data collected during the *Ullrich Water Treatment Plant Site Sound Propagation Study*, a 3D acoustic model was developed using SoundPLAN noise analysis software. Four baseline sound scenarios were developed including normal operations, cleaning of Basin 1, lime blower on the truck, and lime blower in the building. Forty-one (41) acoustic treatments were analyzed as mitigation measures. These alternatives included noise barriers of different locations, heights and lengths as noted in Table ES-1, as well as operation alternatives at the lime blower.

Table ES-1: Noise Barrier Locations & Heights Modeled

Location	Designation	Barrier Heights (ft)	Barrier Length (ft)
On top of Basins 1 and 2	**B**	6, 10, 16	450
Between Ullrich perimeter driveway and fence	**D**	20	140
Along west fence line, west of Basin 1	**F**	12, 20	550
Barrier in the buffer zone	**R**	12, 20, 25	750
Barrier at grade in lawn to reduce vacuum truck noise	**L**	20	80

The most effective treatment for reduction of noise associated with the lime off-loading operation is to utilize the existing lime blower within the building. This measure reduced the sound by over 11dBA as compared to the truck mounted option. AW has recently performed additional maintenance to the indoor lime blower to allow for consistent use of this indoor blower. Additional silencing measures for this blower should be reviewed and alternatives evaluated for further mitigation. Additional silencing at the lime blower was modeled to achieve a further 6 dBA reduction. The costs related to improved silencing of the lime blower would be determined based on the design chosen for implementation.

Barriers along the fence and within the buffer were shown to have limited benefit and the highest cost to implement. The barriers at the top of the basins are most effective at reducing waterfall noise associated with the normal operation and the noise from spraying associated with the basin cleaning. The barriers modeled near the existing driveway and angled between the basins and the building, also reduced the noise from the vacuum truck associated with basin cleaning operations. However, the impacts for these barriers to operations and maintenance could be significant.

To further evaluate noise mitigation at the UWTP, a review of noise mitigation measures with respect to the operations and maintenance impacts should be performed with input from UTWP staff. The proposed barrier design materials should be investigated further for feasibility and structural analysis. Cost estimates should be further refined based on desired barrier location and barrier material. Other site constraints and constructability concerns should also be factored into developing total project cost and schedules for implementation of the alternatives.

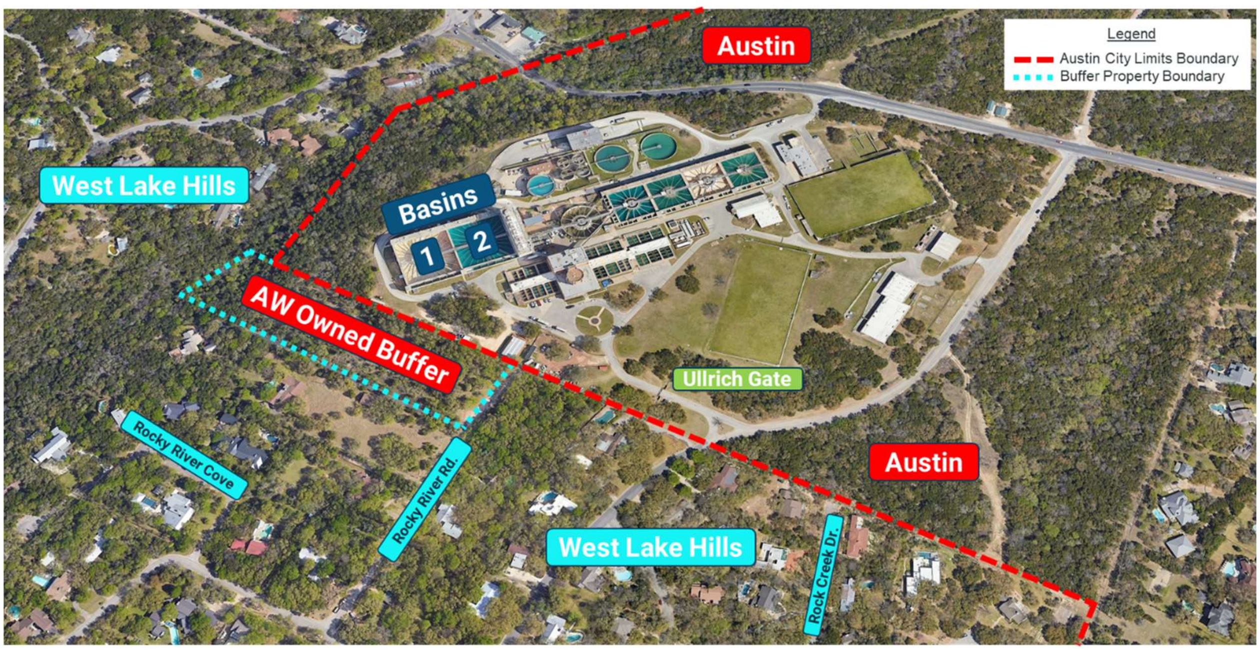
Section 1: Introduction

1.1 Project Background

The Ullrich Water Treatment Plant (UWTP) is located within the City of Austin (COA) and lies adjacent to the City of West Lake Hills (COWLH). The UWTP has the capacity to treat 167 million gallons per day (MGD) of water from the Lower Colorado River. The plant is operated by Austin Water (AW) who also own an adjacent buffer area south of the plant depicted in the aerial view of Figure 1.

In 2022, AW identified the need to perform a site acoustic study at the UWTP to determine sources of sound and ground vibration at the plant which could affect adjacent properties in West Lake Hills. AW retained Kennedy Jenks and Collaboration in Science and Technology (CSTI) to conduct a noise study of the UWTP. A sound measurement plan was developed, with sound and ground vibration data collected in 2022 from various operational activities at the facility. The results of the sound study were presented to AW in a letter report titled "*Ullrich Water Treatment Plant Site Sound Propagation Study",* dated 5 May 2023.

Figure 1: Site Aerial of City Limits Between COA and COWLH



1.2 Summary of Sound Study Results and Measurements

Noise levels presented in the *Ullrich Water Treatment Plant Site Sound Propagation Study* at various locations around the facility are presented in Figure 2 below. Table 1-1 identifies the various sound levels observed for different operations across the site. The majority of sound levels within the Ullrich facility during normal operations are below 70 dBA.

Figure 2: Sound Measurement Locations

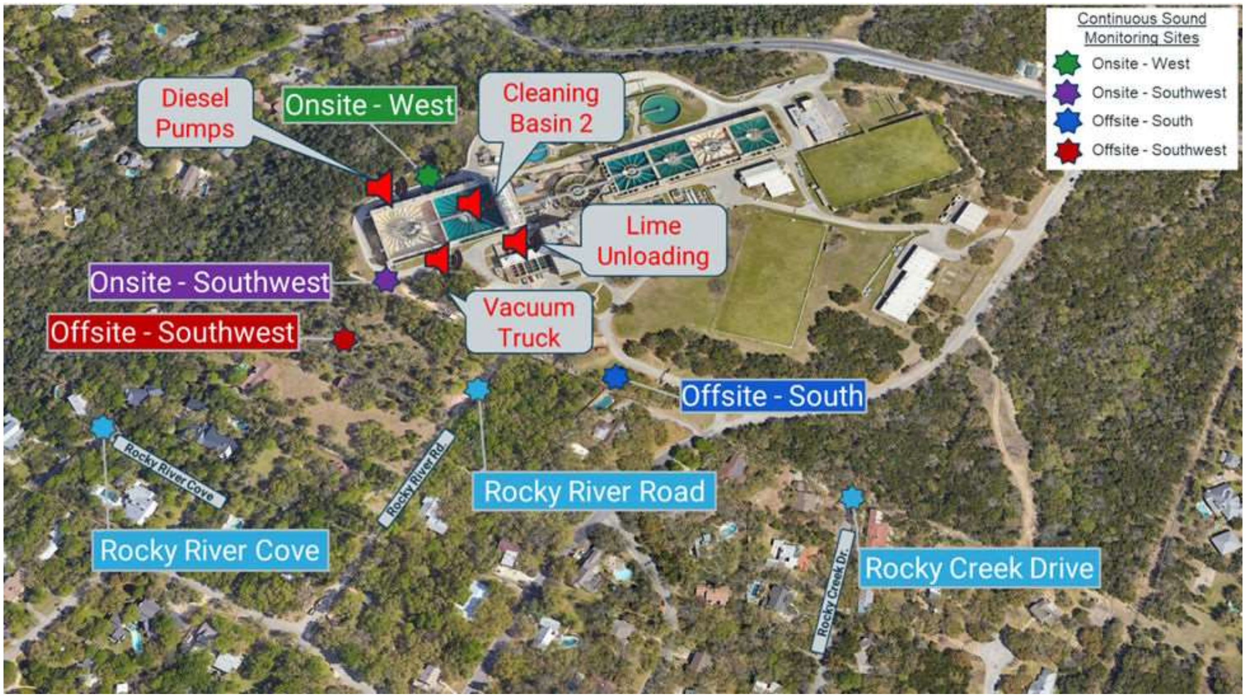


Table 1-1: Summary of Typical Sounds in the Community

	Site						
	Onsite West	Onsite Southwest	Offsite South	Offsite Southwest	Rocky River Rd	Rocky River Cove	Rocky Creek Dr
Condition	**Sound Levels, dBA**						
Normal operations (ambient)	48	47-48	38-43	41-43	38-40	35-42	36-40
Lime Loading w/ truck mounted blower	-	62	53	57	52	45	-
Lime loading w/ indoor blower	-	50	41	47	<47	<41	-
Basin cleaning, diesel pumps	85	-	-	-	-	-	-
Basin cleaning, vacuum truck	-	71	<54	63	52	45	-
Basin cleaning, hydroblasting	-	70-73	55-60	63-66	52-54	46	-

1.3 Project Scope and Study Objectives

After the completion of the *Ullrich Water Treatment Plant Site Sound Propagation Study*, AW requested additional support to prepare an acoustic model of the UWTP and to evaluate noise mitigation alternatives. Using data collected during the *Ullrich Water Treatment Plant Site Sound Propagation Study*, a 3D acoustic model was developed using SoundPLAN noise analysis software. Various alternatives for noise mitigation, including barriers and silencer devices, were modeled in the software.

The objectives of the modeling and noise mitigation analysis performed by Kennedy Jenks and CSTI Acoustics are summarized below:

- Develop acoustic model of the facility
    - Review alternatives to attenuate noise at the facility.
    - Establish minimum sound reduction criteria.
    - Develop baseline acoustic model.
    - Prepare acoustic model of each alternative.
- Review sound mitigation alternatives
    - Analyze acoustic modeling results and attenuation effectiveness.
    - Develop cost information for alternatives.

1.4 Sources of Noise at the UWTP

Certain operations at the UWTP have been identified as being the primary source of unwanted noise which is readily perceptible to nearby neighbors. These sources, which were measured during the *Ullrich Water Treatment Plant Site Sound Propagation Study*, include lime delivery blowers, basin discharge waterfalls, facility operations, running HVAC equipment, truck traffic and the noise associated with the periodic cleaning of the basins by a specialized contractor.

AW is investigating attenuation measures to reduce noise such as providing the lime blower with an enhanced silencer. However, additional sources of noise generated from operations require different mitigation techniques. Additional attenuation can be achieved by providing additional infrastructure, such as barriers or sound absorption panels. This evaluation will model various mitigation alternatives to determine the perceived sound reduction by nearby residents.

Section 2: Baseline Model Development

2.1 Acoustical Modeling Prediction Methods and Limitations

SoundPLAN Noise 9.0, an acoustic 3D sound modeling software, was used to develop alternative models of complex sound propagation using data collected from the *Ullrich Water Treatment Plant Site Sound Propagation Study*. Various barrier locations and heights were modeled in the program to determine the feasibility of different mitigation strategies.

Modeling sound propagation and in particular, sound reflection, assumes perfect material characteristics where no sound passes through the barrier medium. This is generally true for highway noise barriers where any sound that is transmitted through the barrier can be effectively neglected since it will be at such a low level relative to the diffracted sound, i.e., the sound transmitted will typically be at least 20 dBA below that which is diffracted over the top of the barrier (FHWA, 2018). While acoustic modeling of the site provides a good estimate of noise mitigation, it cannot simulate all real-world atmospheric conditions or medium densities.

The modeled effects of different noise-control treatments are expected to be relatively accurate in assessing noise reduction. For example, the model may show a treatment reducing a sound from 55 to 50 dBA, but the actual measured reduction may be from 53 to 48 dBA (still a -5 dBA reduction).

2.2 Baseline Model Development

Baseline sound models without any mitigation measures were developed to compare alternatives. The models simulate normal conditions, different types of lime loading, and basin cleaning operations. In general, the modeled sound levels match the measured sound levels with some minor differences due to the following factors:

- Actual sound levels in the community will vary over time due to changes in weather (especially wind). The modeled sound levels are for typical, no-wind conditions.
- The model does not consider any effects of the trees. In reality, low-frequency sounds travel through trees, but some higher-frequency sounds are reflected by leaves and branches and get scattered in all directions.
- The modeling does not include any background sounds from traffic, planes, insects, birds, etc.

Because Basin 1 is closer to the community, the baseline model used Basin 1 cleaning activities when comparing the effects of different noise treatments. The following figures show the results of the sound modeling without any acoustical treatments.

Table 2-1: Baseline Model Noise Values

	Location R1	Location R3
Noise Source	**Sound Level (dBA)**	**Sound Level (dBA)**
Normal Operating Conditions	<45	<45
Lime Blower on Truck	55-60	<45
Lime Blower in Building	<45	<45
Cleaning of Basin #1	60-65	50-55

Figure 3: Normal Operation (Baseline)

Figure 4: Lime Blower on Truck (Baseline)

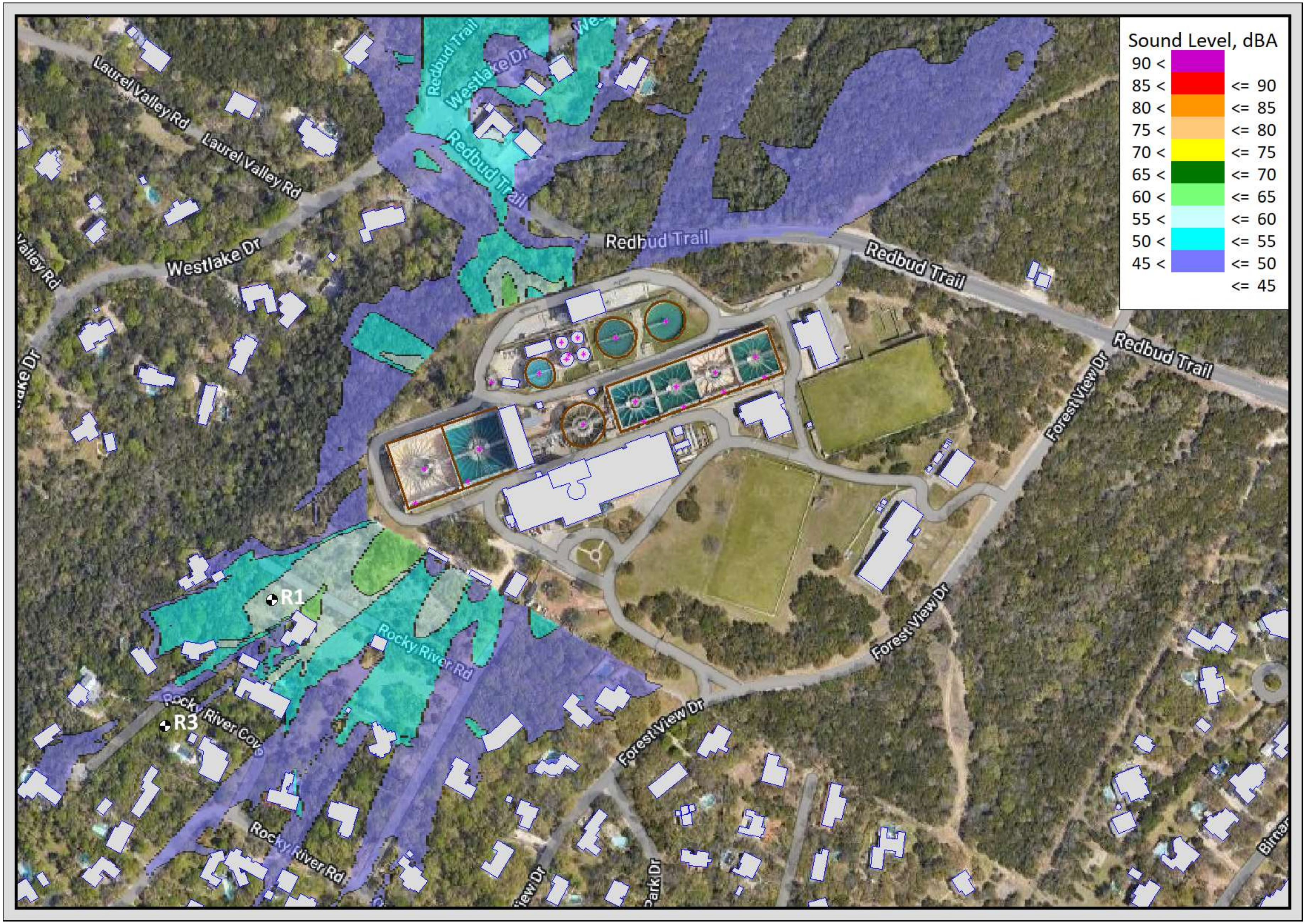
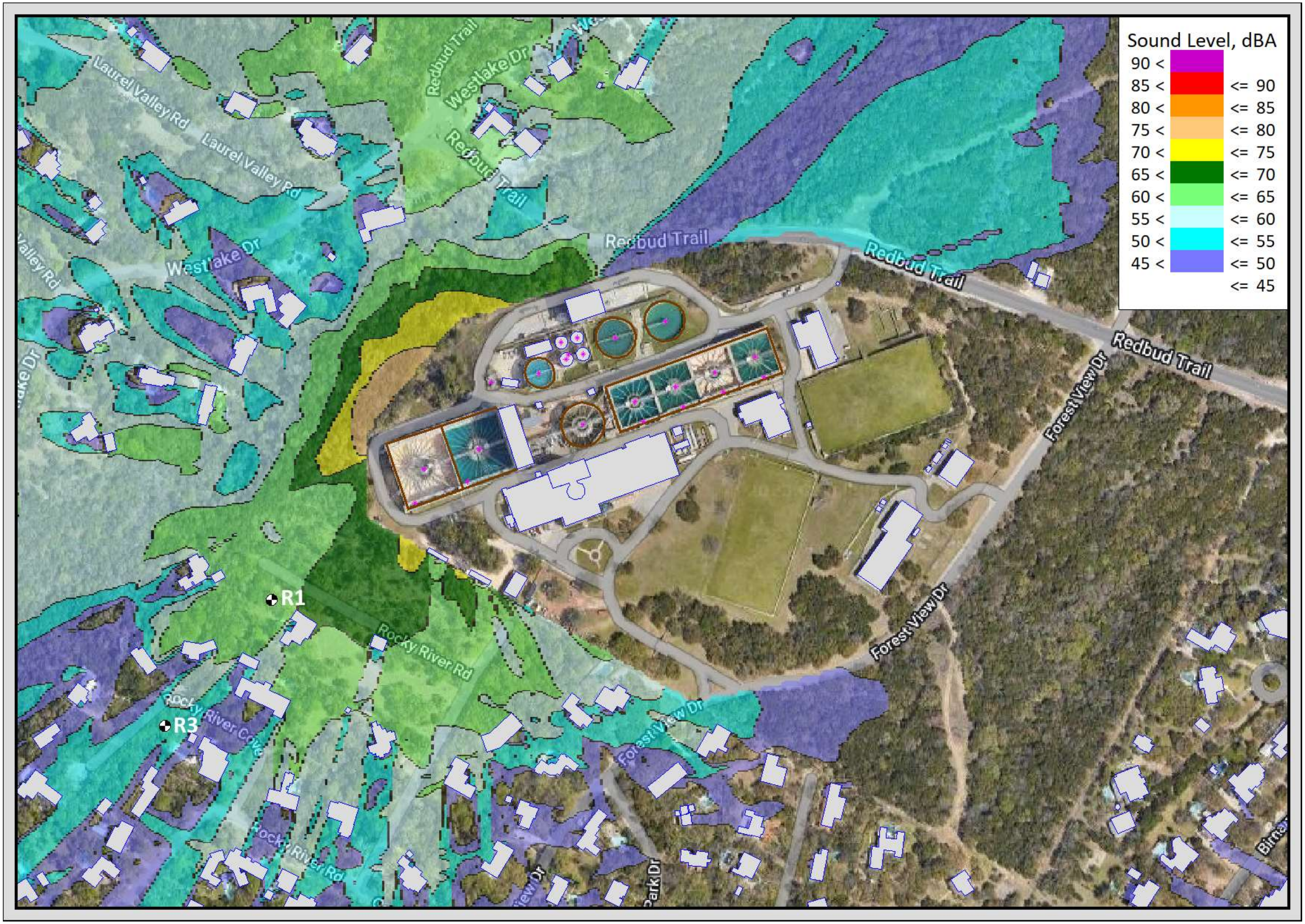


Figure 5: Lime Blower Inside Building (Baseline)

Figure 6: Cleaning Basin 1 (Baseline)



Section 3: Review of Noise Mitigation Measures

3.1 Noise Reduction Design Criteria

Noise reduction design goals will assist in sizing an effective barrier material, height, and location. TxDOT has developed feasibility criteria for acoustic reduction requirements which state a noise abatement treatment is not acoustically effective unless the measure achieves a noise reduction of at least 5 dBA at greater than 50% of first-row impacted receptors and benefits a minimum of two impacted receptors. TxDOT also considers a reduction of at least 7 dBA a substantial noise reduction and is the recommended noise reduction design goal.

A 5 dBA reduction is relatively simple to obtain and is readily perceptible. A 10 dBA reduction is more difficult to achieve but is used frequently as a design goal by authorities because it means the sound would be perceived as half as loud as without the barrier. A 15 dBA reduction is very difficult to achieve because it requires removing 97% of the sound energy and often requires very tall barriers. Finally, a 20 dB reduction is nearly impossible because it requires removing 99% of the sound energy (FHWA, 2018).

Table 3-1: Noise Barrier Design and Insertion Loss

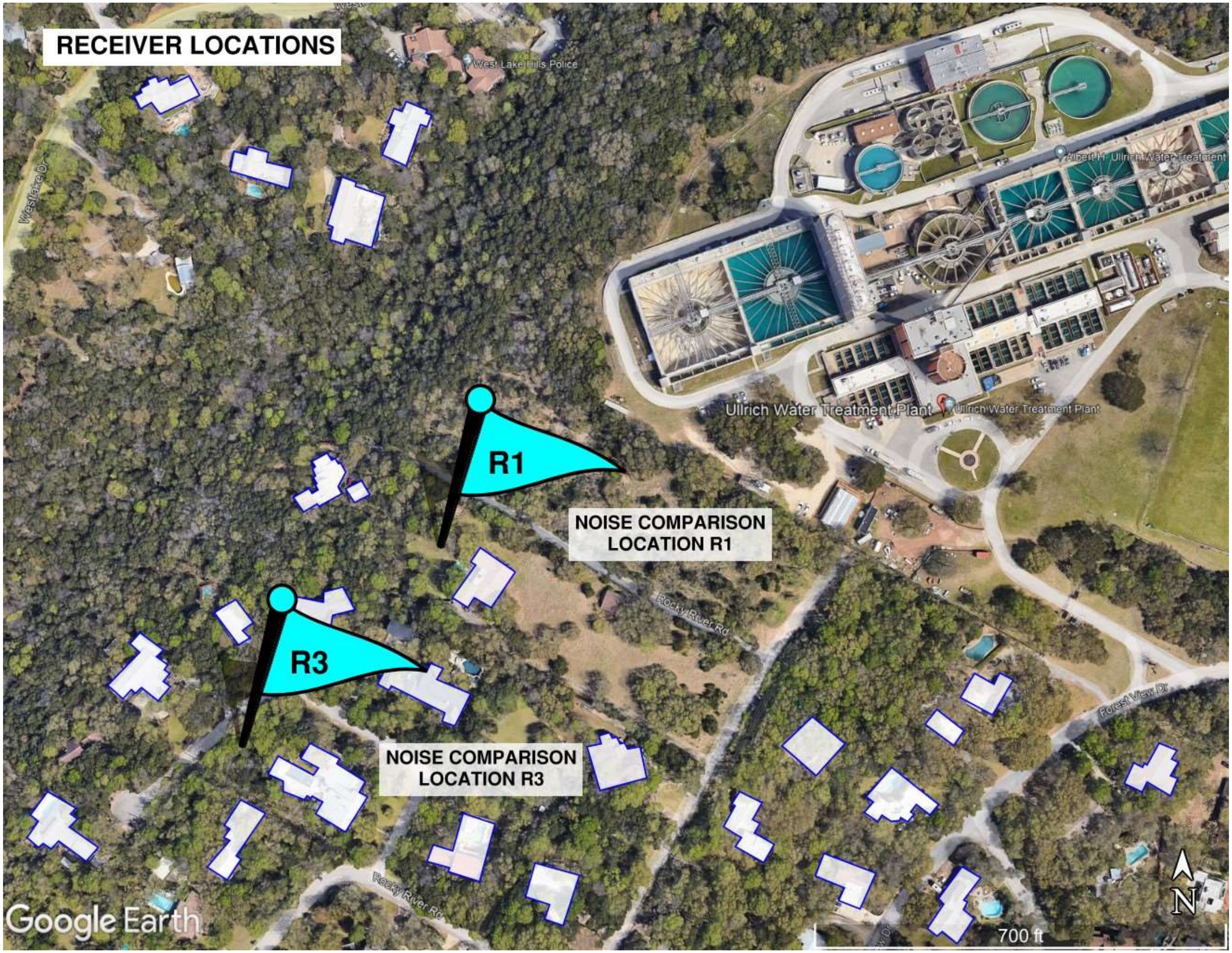
Insertion Loss	Degree of Difficulty	Reduction in Sound Energy	Relative Reduction in Loudness
5 dBA	Simple	68%	Readily Perceptible
10 dBA	Attainable	90%	Half as Loud
15 dBA	Very Difficult	97%	One-third as Loud
20 dBA	Nearly Impossible	99%	One-fourth as Loud

Source: FHWA Noise Barrier Design Handbook

3.2 Noise Receiver Locations Modeled

Results from the acoustic model were evaluated at two locations, R1 and R3 shown in Figure 7. These locations represent the first and third row of homes to the south. These points were selected because southerly homes are most impacted by acoustics during cleaning activities.

Figure 7: Noise Receiver Locations



3.3 Noise Barrier Heights Modeled

Various noise control alternatives were modeled in SoundPLAN, primarily consisting of noise barriers. Different barrier heights were modeled to determine effective treatments. A barrier will only block sound if it blocks line of sight from the source to the receiver. Some sound will still diffract over the top of the barrier, but the higher the barrier, the greater the sound reduction. Barrier heights were limited to a maximum of 25 feet for constructability. The following barrier heights were modeled in the software:

Table 3-2: Barrier Heights Modeled

Location	Designation	Barrier Heights Modeled (ft)
On top of Basins 1 and 2	**B**	6, 10, 16
Between Ullrich perimeter driveway and fence	**D**	20
Along west fence line, west of Basin 1	**F**	12, 20
Barrier in the buffer zone	**R**	12, 20, 25
Barrier at grade in lawn to reduce vacuum truck noise	**L**	20

3.4 Noise Barrier Locations Modeled

Different barrier locations were also modeled in the SoundPLAN software. These barrier locations are shown in the site plan below in Figure 8. Results from the model were analyzed at two different locations in the community, Location R1 at the first row of homes to the south and Location R3 at the third row of homes.

Table 3-3: Barrier Locations and Lengths

Location	Designation	Barrier Length (ft)
On top of Basins 1 and 2	**B**	450
Between Ullrich perimeter driveway and fence	**D**	140
Along west fence line, west of Basin 1	**F**	550
Barrier in the buffer zone	**R**	750
Barrier at grade in lawn to reduce vacuum truck noise	**L**	80

Figure 8: Noise Barrier Locations

3.5 Summary of Modeling Results

A total of 41 acoustic treatments were modeled for four (4) different baseline noise scenarios:

- Lime delivery with blower on truck
- Lime delivery with blower in building
- Cleaning of Basin #1
- Cleaning of Basin #2

Acoustic treatments for cleaning of Basin #1 and lime delivery with a truck-mounted blower are presented below in Figure 9. Both operational scenarios produced the maximum decibel recordings during the sound study, as compared to other operations, and will see the largest benefit from acoustic treatment. Acoustic treatments for the cleaning of Basin #1 will also mitigate the other operational noise sources, such as waterfalls, that have been identified as an operational noise of concern. A full list of scenarios and model results can be found in the CSTI report available in Appendix I.

Lime Blower Treatments: The blower treatments (using the blower within the building and improving the silencer on this blower) are very effective at reducing noise from the lime blowing operations.

Basin Barrier B: This barrier is effective at reducing noise from the spray cleaning of the basins and the basin waterfalls but has no effect on most other noises. Taller barriers are better than lower barriers, but even a 6-ft tall barrier provides good reduction of the spraying noise. If an additional treatment (Barrier L or D) is used to reduce the vacuum noise, a 10-ft wall for the Basin Barrier is 2-to-3 dBA more effective than a 6-ft wall at reducing noise from Basin 1 cleaning. This barrier is more effective with the cleaning of Basin 1 than the cleaning of Basin 2 (which is further away from the barrier).

Lime Building Sound Absorption: This treatment reduces sound reflections off the building and has a minor benefit (about 1 dBA) during the cleaning of Basin 2 but has no benefit for any other noises including the cleaning of Basin 1.

Fenceline Barrier F: This barrier is moderately effective at reducing some noises at the first row of houses but has very little benefit further into the neighborhood.

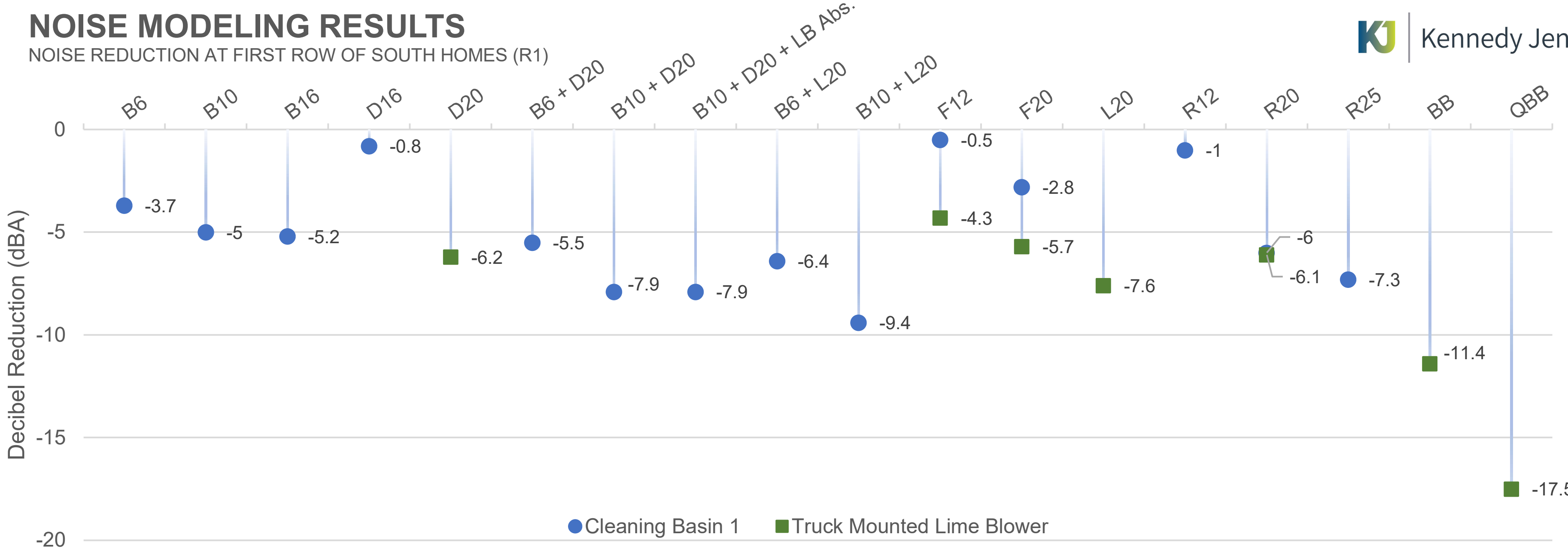
Barrier R nearest Residences: This barrier is moderately effective at reducing some noises at the first row of houses but has very little benefit further into the neighborhood. A taller barrier (20 ft) is better than a lower barrier (12 ft), but the benefits do not extend far into the neighborhood. Increasing the wall height from 20 to 25 ft has about a 1 dBA benefit.

Barrier D by Ullrich Perimeter Driveway: This barrier has some benefit for the lime blower and the vacuum truck. It will also provide benefit for other noises propagating down the alley within the treatment plant such as noise from trucks and the basin cleaning of Basin 4.

Barrier L by Lawn and Perimeter Driveway: This barrier reduces noise from the lime blower and the vacuum truck. Like Barrier D, it will also provide benefit for other noises propagating down the alley within the treatment plant such as noise from trucks and the basin cleaning of Basin 4. Because the current lawn area between Basins 1 and 2 and the Ullrich driveway are narrow, this treatment is most effective if the driveway is relocated further from the basins to allow room for a longer barrier.

NOISE MODELING RESULTS

NOISE REDUCTION AT FIRST ROW OF SOUTH HOMES (R1)



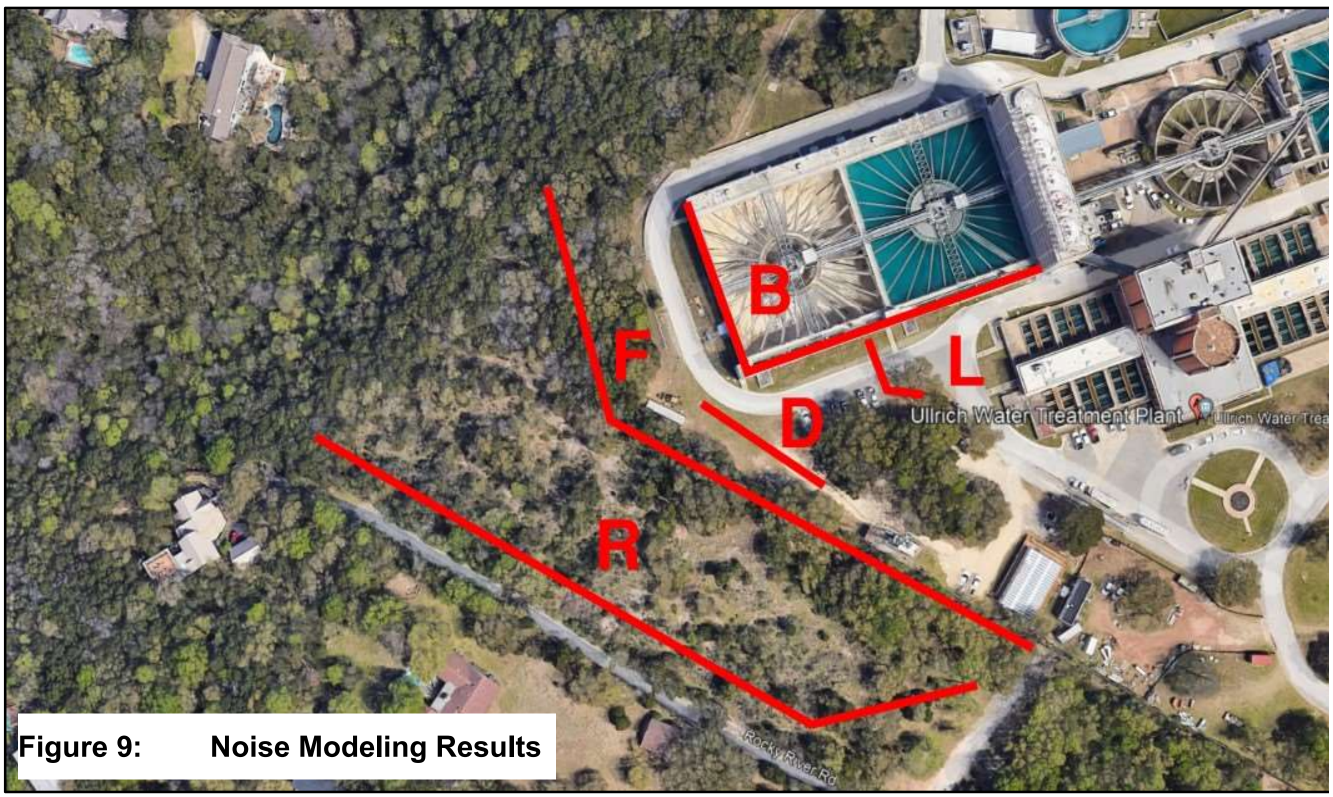


Figure 9: Noise Modeling Results

LEGEND

- "B6" Notation = 6 ft high wall at Location B
- BB = building blower treatment (instead of using truck-mounted blower)
- QBB = Quiet Building Blower (better silencer on building blower)
- LB Abs = Sound absorption on the west face of the Lime Building (near Basin 2)

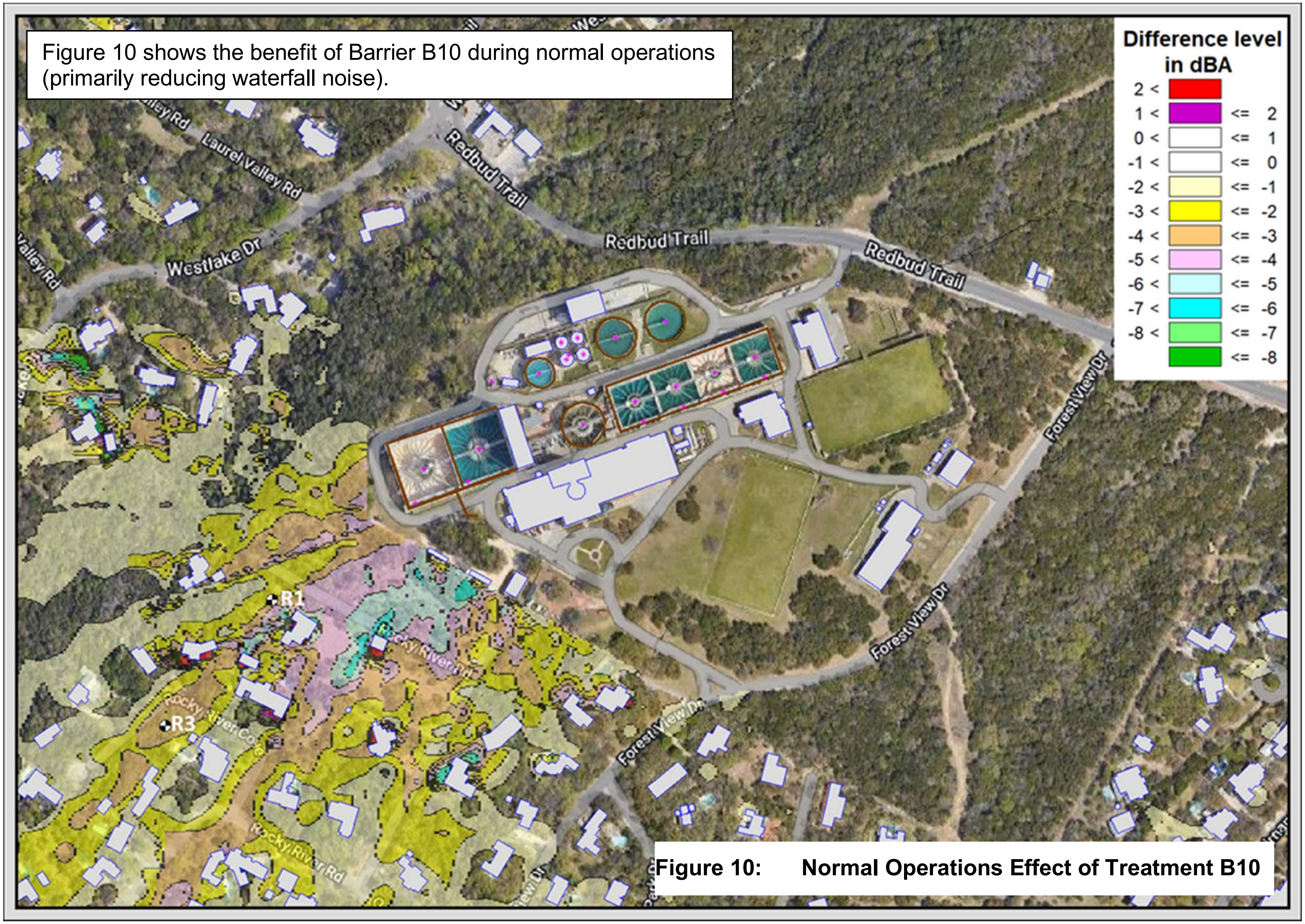


Figure 10: Normal Operations Effect of Treatment B10

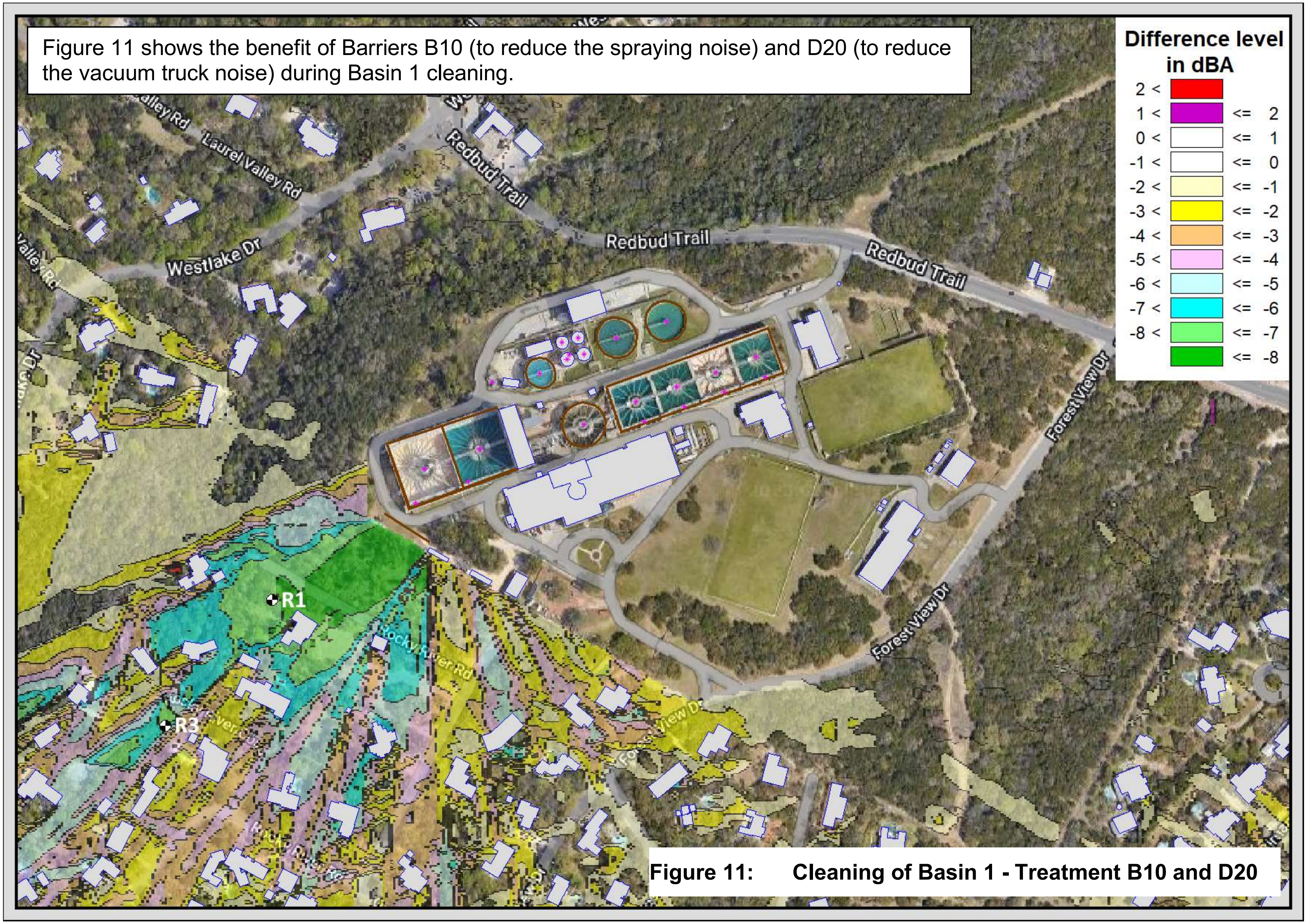


Figure 11: Cleaning of Basin 1 - Treatment B10 and D20

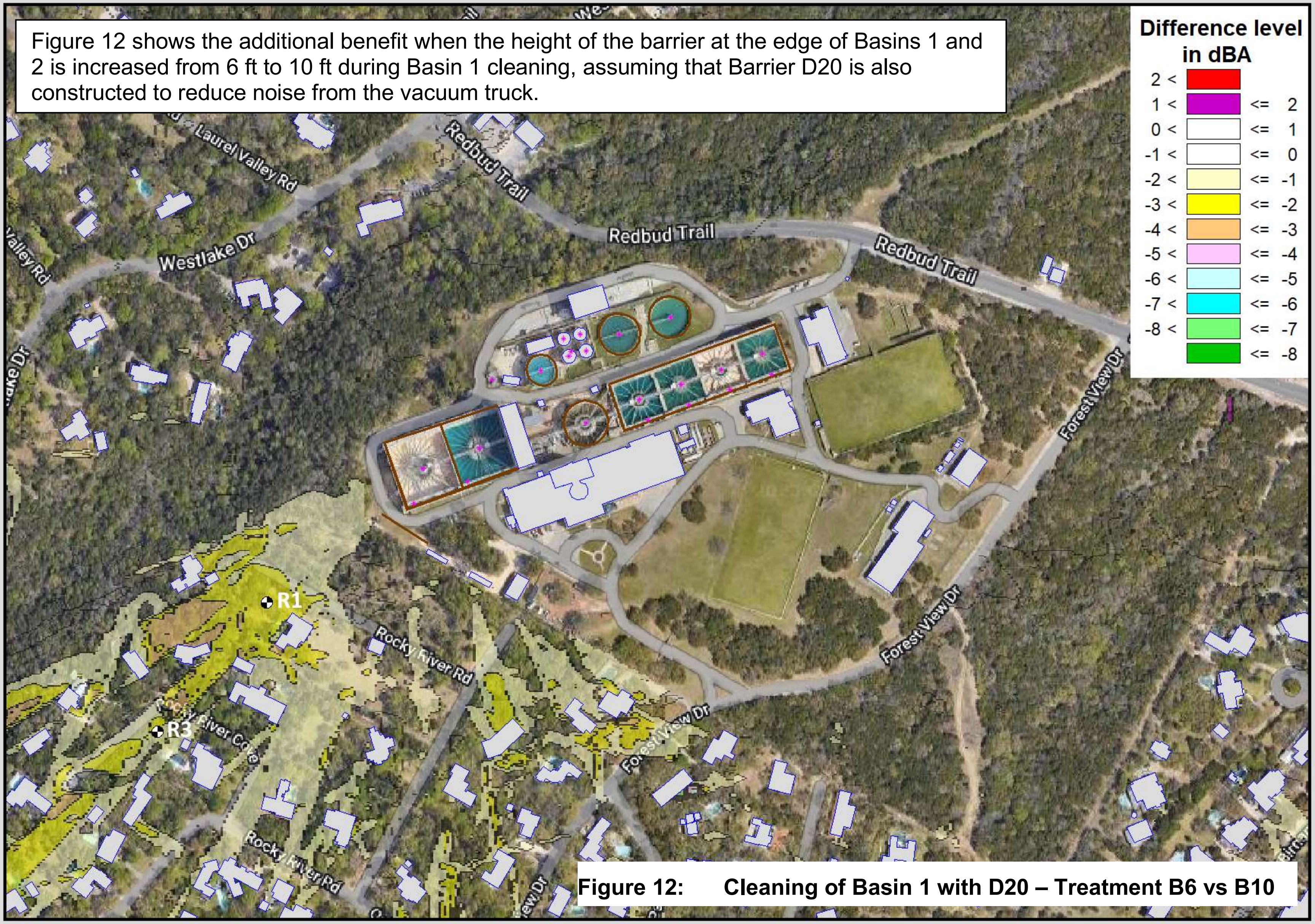


Figure 12: Cleaning of Basin 1 with D20 – Treatment B6 vs B10

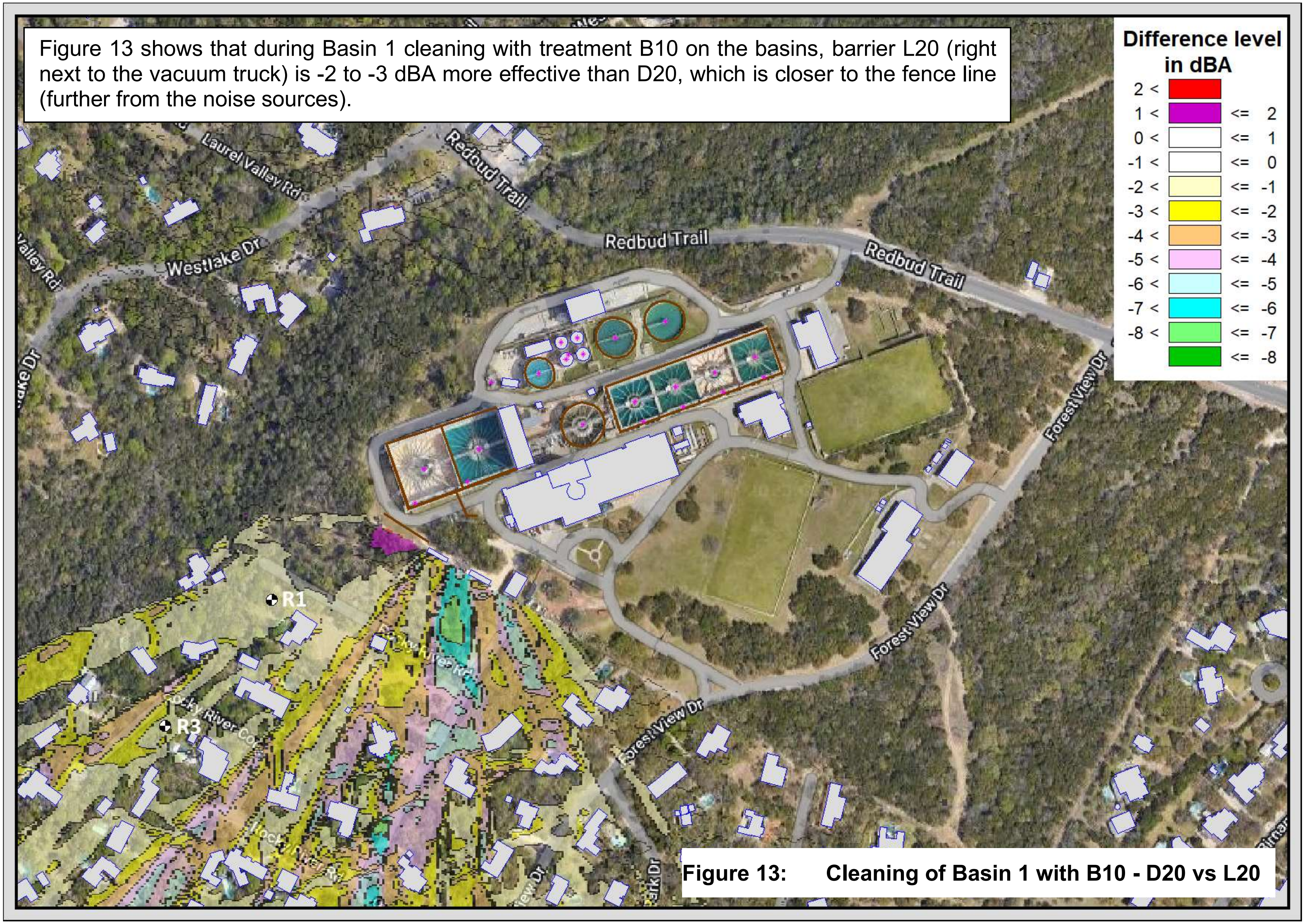


Figure 13: Cleaning of Basin 1 with B10 - D20 vs L20

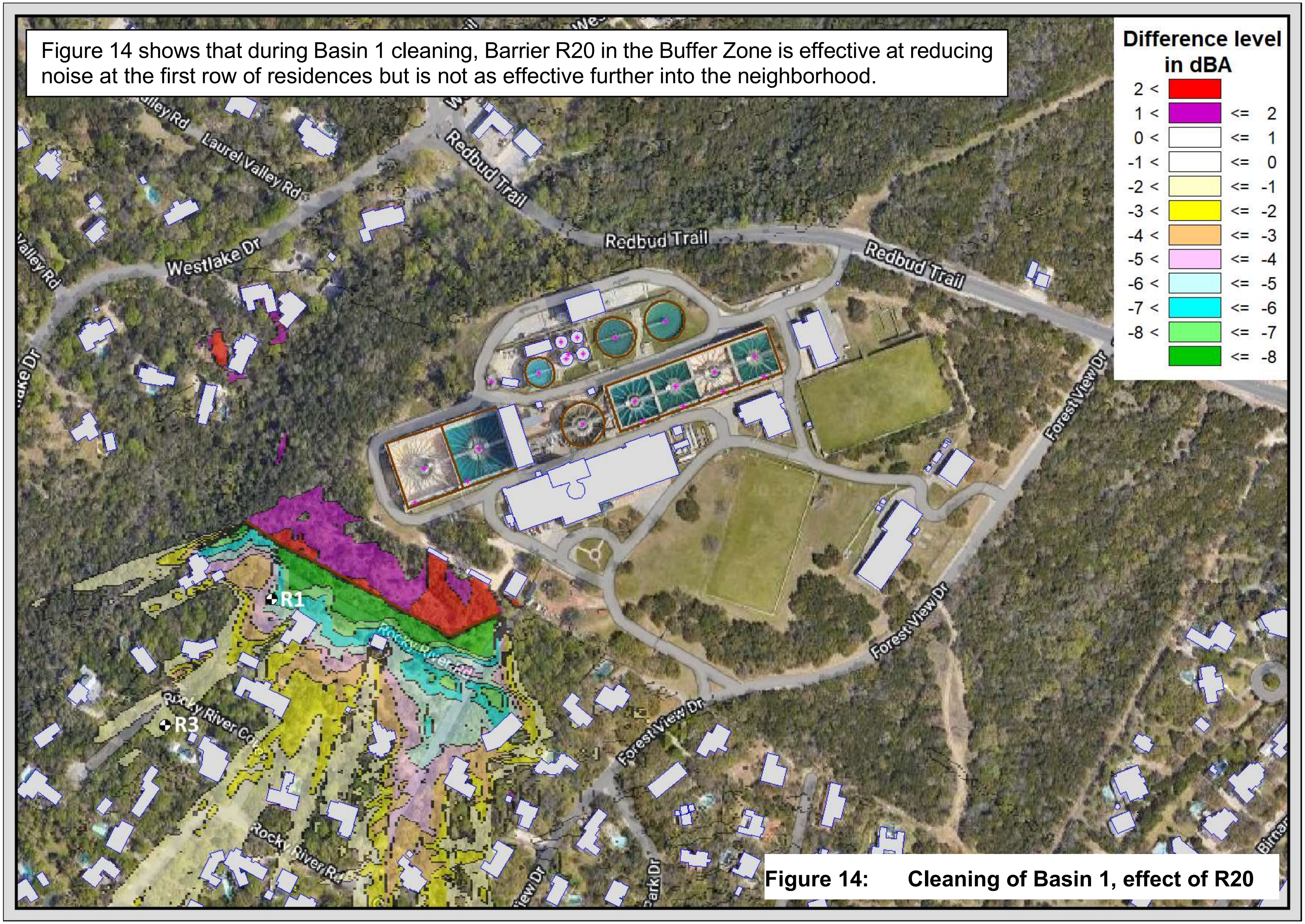


Figure 14: Cleaning of Basin 1, effect of R20

Section 4: Review of Noise Mitigation Measures

4.1 Barrier Materials

Noise barrier materials are normally selected based on several factors including aesthetics, durability, cost, and transmission loss. Transmission loss is the loss in sound energy, expressed in decibels, as sound passes through a barrier of wall. The value of transmission loss is intrinsic to the material properties such as density and thickness. As a rule of thumb, any material weighing at least 4 lbs/ft^2 has a transmission loss of at least 20 dBA. Such a material would also be adequate for a noise reduction of at least 10 dBA due to diffraction (FHWA, 2018).

In most cases the maximum transmission loss and noise reduction that can be achieved by a barrier is approximately 20 dBA for thin walls and 23 dBA for berms. A material that has a transmission loss of at least 25 dBA or greater is desired and always adequate for a noise barrier. Common barrier materials and their transmission loss are shown below in Table 4-1.

Table 4-1: Approximate Sound Transmission Loss for Common Materials

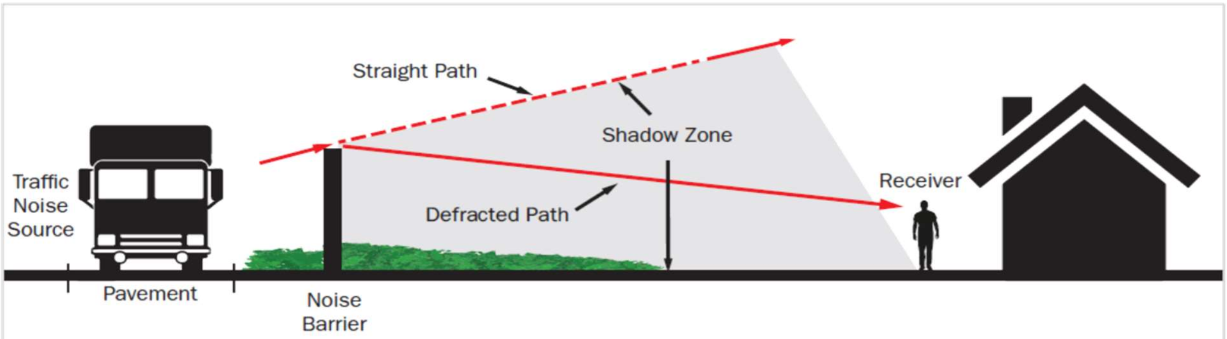
Material	Thickness (in)	Weight (lb/ft^2)	Transmission Loss (dBA)
Concrete Block	8”	31	34
Dense Concrete	4”	50	40
Light Concrete	4”	33	36
Steel (22 ga)	0.0312”	1.25	20
Aluminum Sheet	0.125”	1.8	25
Wood (fir)	1”	3.3	21
Plywood	0.5”	1.7	20
Plexiglass	0.25”	1.5	22

Source: FHWA Noise Barrier Design Handbook

4.2 Barrier Heights

Traditional barriers constructed of concrete reflect, refract, and transmit (reduce sound energy passing through the barrier medium) acoustic waves. For concrete barriers, any sound transmitted directly through the barrier is typically neglected since it is at such a low level relative to the diffracted sound. Diffraction, or the bending of sound waves around an obstacle, can occur at the top of the barrier or around the sides. Sound energy that is diffracted over the top of the barrier is still reduced because the barrier forces sound waves to take a longer path. Barrier height, relative to the sound source, plays an important role in determining how much acoustic energy is diffracted. Receptors lower in elevation to the noise source are located in the shadow zone, see Figure 15 below. Acoustic energy is significantly reduced in the shadow zone due to diffraction. Receptors located in this region are most benefited from noise barriers.

Figure 15: Diffraction of Sound Waves over Barrier



Source: TxDOT Traffic Noise Policy Implementation Guidance

Typically, the maximum constructible barrier height is 20 feet. Common barrier sizes range between 6 and 20 feet tall. Often it is impractical to construct very tall barriers due to diminishing effectiveness of sound reduction and due to the increased cost for the structural requirements for these barriers. However, noise barriers should be tall enough and long enough that only a small portion of sound diffracts around the edges. Typically, each additional meter of barrier height above line-of-sight blockage will provide about 1.5 dBA of additional attenuation. A maximum barrier height of 25 feet was established as the upper boundary condition.

4.3 Barrier Location

Noise barriers are generally most effective when they are close to the sound source or close to the receptor. Locating a barrier at the most acoustically effective location is critical to accurately assess whether a barrier meets feasibility and effectiveness criteria. If the sound source is located on fill and the receptors are depressed below, the most effective location is often near the sound source. The opposite is true if receptors are located above the sound source.

The UWTP is located on an embankment with residences to the west being 30 to 50 feet lower in elevation; these residences are in a shadow zone. Because of this, western residences are less susceptible to sound propagation from basin cleaning activities as sound is diffracted over the basin wall and its energy is significantly reduced as it travels to lower elevation. In contrast, residences to the south are at approximately the same elevation as the top of the basin walls and more susceptible to noise generated from the plant. Homes located to the east of Rocky River Road are less affected than south and westerly directions due to being farther away from the noise source (basins) and the surrounding geography reduces line of sight which mitigates propagation.

4.4 Summary of Acoustical Considerations for Noise Barriers

Criterion	Consideration
Barrier Material	Barrier panel materials should be at least 4 lb/ft^2 and have a transmission loss of 20 dBA through the material
Barrier Height and Length	Ensure barrier height and length are such that only a small portion of sound diffracts around the edges. Barrier heights should be tall enough so that receptors are located in the shadow zone, where acoustic energy is reduced the most
Barrier Location	Barriers should block line of sight to the noise source. Receptors located below the noise source are most benefited from barriers being located near the noise source. Receptors located above the noise source are most benefited from barriers located near the receptor.

4.5 Traditional Noise Barrier Walls

The most common acoustic barriers are ground mounted type systems including noise berms, noise walls or a combination of the two.

4.5.1 Noise Berms

Noise berms often provide an additional 1-3 dBA of attenuation compared to barrier walls. Berms are constructed from natural earthen materials such as soil, rock or stone. Slopes are typically 2:1 or greater to maintain stability of the structure. While berms are effective in reducing noise, standalone berms are not recommended for implementation at the UWTP. The closest impacted southern receptors are situated at approximately the same elevation as the top of Basin 1, with good line of sight to the plant. A noise barrier berm would need to be a minimum of 25 feet tall, located at the fence line or in the COA owned buffer to achieve the recommended 7 dBA reduction. This sized berm, with 2:1 side slopes, is impractical from a construction standpoint and has negative aesthetic and environmental effects.

Figure 16: Noise Barrier Berm

Source: Wisconsin DOT

4.5.2 Noise Walls – Post and Panel

Post and panel noise barriers are typically fabricated offsite and then assembled onsite. This type of barrier consists of panels mounted between foundation supported posts. Primary elements include the post and foundation attachments, panels, and panel to post connections. Foundations can either be concrete cylinder (caisson), spread footing, or continuous footing. When designing post and panel barriers, careful consideration must be given to horizontal joints between panels to avoid sound leaks due to gaps.

The possibility of a barrier panel being damaged and needing replacement should be considered when choosing a panel type. When damage occurs at the bottom of the panel bay, it is likely that all stacked panels need to be removed and reset. This type of barrier system is suitable for location at basin 1. These systems are often limited in height due to wind load transfer.

Figure 17: Example Post and Panel Noise Barriers

4.5.3 Gabion Stone Walls

This type of barrier system is comprised of crushed rock contained in large rectangular baskets made of wire mesh. These baskets sit on top of each other in a pyramid fashion to obtain required barrier height and stability. Baskets are well draining, economical, frost resistant and well suited for rolling topography. Baskets can be free standing without foundations. This type of barrier is well suited for locations in the COA owned buffer or along the fence line but may not meet aesthetic requirements for the community.

Figure 18: Gabion Stone Noise Barriers

4.6 Sound Absorptive Materials – Acoustic Panels

Noise barriers reduce sound by either absorbing it, transmitting it, reflecting it, or forcing it to take a longer path (refracting it). A barrier without any absorptive treatment, is by default reflective. A reflective barrier, such as a pre-cast post and panel wall, will reflect some sound energy back towards the source. Reflection can cause negative impacts for parallel barrier systems by reducing the effectiveness of insertion loss through the barrier medium.

For the UWTP, if a barrier is constructed at the western edge of Basin 1, some reflection will occur back towards the lime building. To mitigate reflection, absorptive materials may be applied to the barrier façade or the lime building. Absorptive materials can include high-density wool, perforated aluminum blocks, or specially designed acoustic blankets. Absorptive treatments are an added cost and may always be installed post construction if required. Innovative sound barriers using absorptive materials are presented below in Figure 19.

Figure 19: Absorptive Noise Barrier Walls

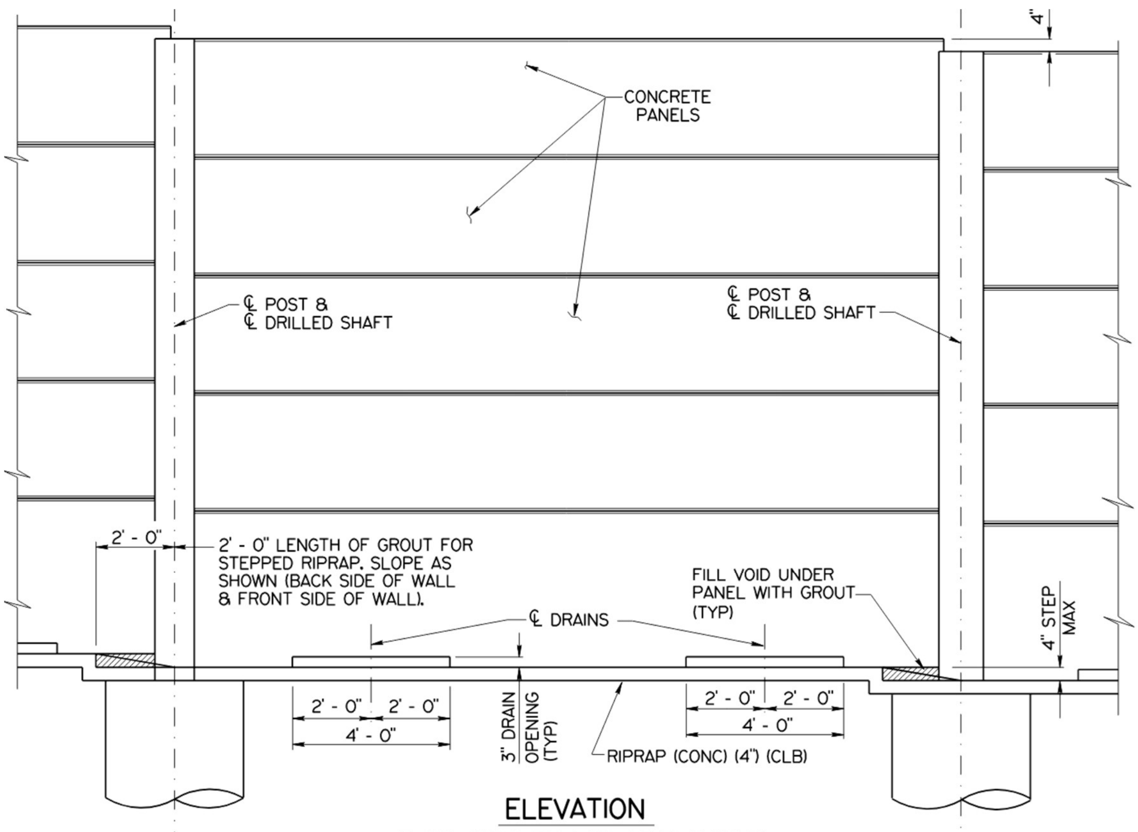
(Left) Perforated aluminum blocks with high density mineral wool in the cavity.
(Right) Galvanized steel panels with absorptive surface treatment
(Bottom) Vinyl-coated polyester, 2”-thick, 1.2 lb-psf, quilted sound barrier blankets for temporary use.

Section 5: Implementation and Costs Evaluation

5.1 Barrier Construction

Although there are various materials that can be used for noise barriers many are post and panel style constructed of precast concrete. Concrete is durable, versatile, and well suited to reduce sound transmission, even at a thickness of only 0.5-inches. Concrete is rugged and able to withstand severe temperatures which give it a long design life. A precast post and panel barrier design was assumed to be the type of barrier that may be selected for implementation at ground level near the fence line or buffer zone. A typical barrier design that may be applicable to the UWTP is presented below in Figure 20.

Figure 20: Post and Panel Noise Barrier Wall



Source: TxDOT

5.2 Cost Evaluation

Barriers at ground level were assumed to be post and panel precast concrete. Barriers on top of the basins were assumed to be 22-gauge steel. Concept level screening estimates were developed for each individual barrier option in accordance with the Association for the

Advancement of Cost Engineering Class 4 are presented in Table 5-1 below. Costs include a 30% contingency factor in conformity with the Class 4 estimate criteria which has an accuracy range of +20% to +50% and -15% to -30%. Unit bid pricing was gleaned from the previous 18 months of TxDOT bid item averages for sound walls. Additional costs were gathered from database sources such as RSmeans. Costs include both direct construction costs and indirect costs such as mobilization, Division 1, contractor overhead and profit, and construction contingency. Costs for the combination alternatives can be assessed by combining the proposed cost for individual alternatives together. A Class 4 cost estimate was not developed for the quieter building blower alternative since additional engineering analysis would be required, which is outside the scope of this project. Analysis for the improved silencing would include review of as-built drawings and original submittals for existing blower, sizing and recommending a new proposed silencing device or material, and evaluation of any additional building requirements for installation. However, the cost of this improved silencing is anticipated to be less than the cost of the barrier alternatives listed below.

Table 5-1: Opinion of Probable Construction Cost

Location	Height	Length	Material	Estimated Project Cost		
				+50%	Total Est*	-30%
B	6 ft	450 ft	Steel	$325,500	$217,000	$151,900
B	10 ft	450 ft	Steel	$516,000	$344,000	$240,800
B	16 ft	450 ft	Steel	$808,500	$539,000	$377,300
D	16 ft	140 ft	Concrete	$562,500	$375,000	$262,500
F	12 ft	550 ft	Concrete	$1,431,000	$954,000	$667,800
F	20 ft	550 ft	Concrete	$3,103,500	$2,069,000	$1,448,300
R	12 ft	750 ft	Concrete	$1,948,500	$1,299,000	$909,300
R	20 ft	750 ft	Concrete	$2,277,000	$1,518,000	$1,062,600
R	25 ft	750 ft	Concrete	$3,793,500	$2,529,000	$1,770,300
L	20 ft	100 ft	Concrete	$414,000	$276,000	$193,200

* Costs do not include costs for design, bidding, permitting, or construction management.

Each alternative was also evaluated by determining the cost per decibel reduced. The cost metric is presented below in Table 5-2.

Table 5-2: Cost per dBA Reduced

Location	Height	Length	Operating Scenario	dBA Reduction	Cost per 1 dBA Reduced
B	6 ft	450 ft	Basin 1 Cleaning	-3.7	$58,649
B	10 ft	450 ft	Basin 1 Cleaning	-5	$68,800
B	16 ft	450 ft	Basin 1 Cleaning	-5.2	$103,654
D	16 ft	140 ft	Basin 1 Cleaning	-0.8	$468,750
F	12 ft	550 ft	Basin 1 Cleaning	-0.5	$1,908,000
F	20 ft	550 ft	Basin 1 Cleaning	-2.8	$738,929
R	12 ft	750 ft	Basin 1 Cleaning	-1	$1,299,000
R	20 ft	750 ft	Basin 1 Cleaning	-6	$253,000
R	25 ft	750 ft	Basin 1 Cleaning	-7.3	$346,438
L	20 ft	100 ft	Truck Lime Blower	-7.6	$36,316

5.3 Recommendations for Additional Study

The most effective treatment for reduction of noise associated with the lime off-loading operation is to utilize the existing lime blower within the building. This measure reduced the sound by over 11dBA as compared to the truck mounted option. AW has recently performed additional maintenance to the indoor lime blower to allow for consistent use of this indoor blower. Additional silencing measures for this blower should be reviewed, and alternatives evaluated to achieve further mitigation. Additional silencing was modeled to achieve a further 6 dBA reduction. The costs related to an improved silencing alternative would be determined based on the design chosen for implementation.

Barriers along the fence and within the buffer were shown to have limited benefit and the highest cost to implement. The barriers at the top of the basins are most effective at reducing waterfall noise associated with the normal operation and the noise from spraying associated with the basin cleaning. The barriers modeled at L and D, which were near the existing driveway and angled between the basins and the building, also reduced the noise from the vacuum truck associated with basin cleaning operations. However, the impacts for these barriers to operations and maintenance could be significant.

To further evaluate noise mitigation at the UWTP, a review of noise mitigation measures with respect to the operations and maintenance impacts should be performed with input from UTWP staff. The proposed barrier design materials should be investigated in conjunction with the post and panel style barriers presented in this report. Preliminary design of temporary sound walls on top of Basin 1 should be reviewed in more detail, as the feasibility of these alternatives for structural design was not completed. Cost estimates should be further refined based on desired barrier location and barrier material. Other site constraints and constructability concerns should also be factored into developing total project cost and schedules for implementation of the alternatives.

References

US. Federal Transit Administration. Office of Planning and Environment. Transit Noise and vibration Impact Assessment. By Carl E. Hanson, David A. Towers, and Lance D. Meister. FTA-VA-90-1003-06. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/FTA_Noise_and_Vibration_Manual.pdf

US Department of Transportation Federal Highway Administration. FWHA Noise Barrier Design Handbook 2018. By US Department of Transportation FHWA-EP-00-005. 1. Introduction - Design - Design Construction - Noise Barriers - Noise - Environment - FHWA (dot.gov)

Appendix I: CSTI Report No. R-1310

Collaboration in Science and Technology Inc.
CONSULTANTS IN ACOUSTICS, NOISE, AND VIBRATION

AUSTIN ULLRICH WTP NOISE MODELING STUDY

CSTI REPORT NO. R-1310-0
CSTI PROJECT NO. 6869

1 SEPTEMBER 2023

Prepared By:
CSTI acoustics

Prepared For:
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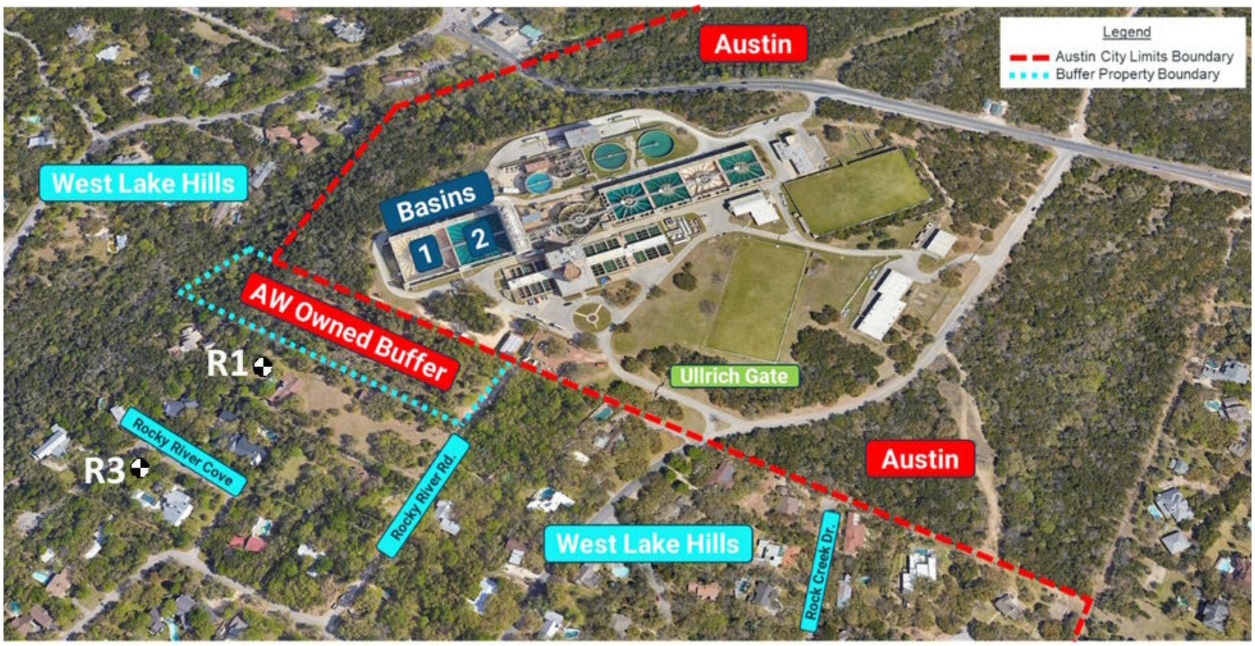
1. INTRODUCTION

Collaboration in Science and Technology Inc. (CSTI) was retained by Kennedy/Jenks on behalf of the City of Austin to conduct a noise study of the Ullrich Water Treatment Plant (WTP) located in Austin, TX. In Phase 1 of the study, detailed sound measurements were made within the facility and in the surrounding community. Recent work discussed in this report consisted of creating a computer noise model to calculate community sound levels based on our previous sound measurements and then modeling different options for noise control.

2 SITE DESCRIPTION

The Ullrich Water Treatment Plant is located with all its equipment within the Austin city limits. The site property line to the northwest and southwest is adjacent to the city limits of the City of West Lake Hills, and the nearest residences are within West Lake Hills. Austin Water also owns a buffer zone to the south of the facility. Figure 1 presents an aerial view of the WTP and surrounding neighborhood. R1 and R3 are sound modeling locations in the community.

Figure 1. Aerial View of Ullrich Facility



3 NOISE CRITERIA

Though the Ullrich facility is located within the Austin city limits, the nearest residences are located within the City of West Lake Hills.

Section 25-2-1067 (B) of the Austin Ordinance, Design Regulations states that “The noise level of mechanical equipment may not exceed 70 db at the property line.” Elsewhere in the ordinance, “dB” is defined as “dBA”. This 70-dBA ordinance was referenced in the previous Nelson noise study.

The City of West Lake Hills Code of Ordinances Article 12.02 prohibits “any unreasonably loud, disturbing, unnecessary noise which causes material distress, discomfort or injury to persons of ordinary sensibilities” and also prohibits “any noise of such character, intensity and continued duration, which substantially interferes with the comfortable enjoyment of private homes by persons of ordinary sensibilities”. Ordinances §24.02.003(1) references the maximum permissible sound pressure levels using frequency bands which have not been used since the 1960s and cannot be measured with any available, calibrated sound meters.

4 SUMMARY OF SOUND MEASUREMENTS

Arno Bommer of CSTI acoustics conducted sound measurements at the Ullrich facility on November 17 to 21, 2022. We measured normal operations, lime loading, and basin cleaning performed on Basin 2.

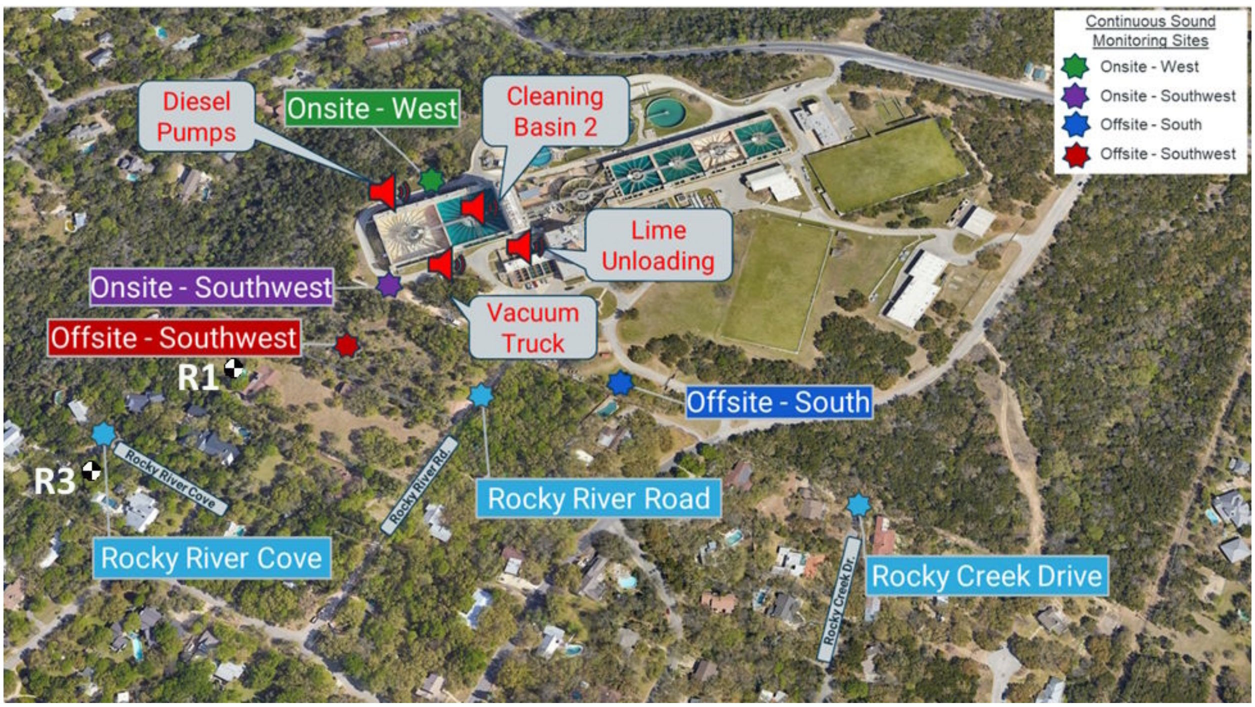
The facility uses lime in water treatment. Lime is delivered by trucks, normally in the morning on weekdays. Until fall 2022, blowers mounted on the trucks were used to convey lime into storage silos inside a building. To reduce the noise of a truck-mounted blower, a permanent blower was installed inside an acoustically treated room inside the building.

There are several major noise sources associated with the basin cleaning:

- Water is pressurized with diesel-powered pumps (up to 4 running at a time).
- Water is sprayed at high pressure to remove lime scale from basin surfaces.
- The water and scale residue are then vacuumed from the bottom of the basin using a truck-mounted vacuum.

Figure 2 presents the main sound-measurement locations at the fence line and in the surrounding community.

Figure 2. Sound Measurement Locations



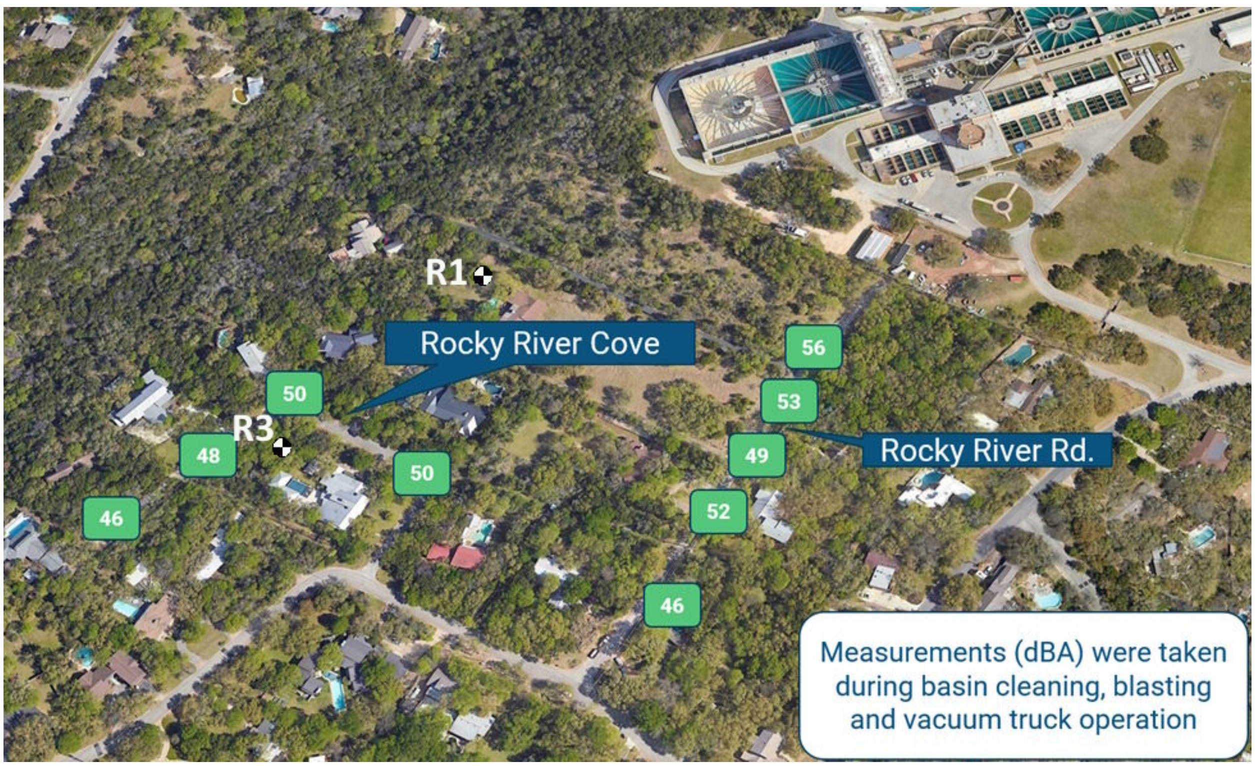
The following table summarizes the sound levels from different operations at the locations shown in the previous figure:

Table 1. Summary of Sound Measurements

Condition:	Site						
	Onsite - West	Onsite - Southwest	Offsite - South	Offsite - Southwest	Rocky River Rd	Rocky River Cove	Rocky Creek Dr
	Sound Levels, dBA						
Ambient (normal operations)	48	47-48	38-43	41-43	38-40	35-42	36-40
Lime Loading Truck mounted blower	-	62	53	57	52	45	-
Lime Loading w/ building blower	-	50	41	47	<47	<41	-
Basin Cleaning - Diesel pumps	85	-	-	-	-	-	-
Basin Cleaning- Vacuum Truck	-	71	<54	63	52	45	-
Basin Cleaning- Hydroblasting	-	70-73	55-60	63-66	52-54	46	-

The following figure presents the A-weighted sound levels (dBA) measured in the community during Basin 2 cleaning with the vacuum truck operating. This was the loudest scenario during the sound measurements. As shown, sound levels generally decrease with increases in distance from the facility.

Figure 3. Sound Levels Measured in Community



5 SOUND MODELING WITHOUT TREATMENTS

The sound-measurement data from November 2022 were used to create a 3D computer model of the facility. The model can simulate normal conditions, different types of lime loading, and basin cleaning operations. In general, the modeled sound levels match the measured sound levels with some minor differences due to the following factors:

- Actual sound levels in the community will vary over time due to changes in weather (especially wind). The modeled sound levels are for typical, no-wind conditions.
- The model does not consider any effects of the trees. In reality, low-frequency sounds travel through trees, but some higher-frequency sounds are reflected by leaves and branches and get scattered in all directions.
- The modeling does not include any background sounds from traffic, planes, insects, birds, etc.

Although the modeled sounds are not 100% accurate, we expect that the modeled effects of different noise-control treatments will be accurate. For example, the model might show a treatment reducing the sound level from 55 to 50 dBA, but the actual measured reduction may be from 53 to 48 dBA (still a 5-dBA reduction).

During the November 2022 sound measurements, Basin 2 was being cleaned. Because Basin 1 is closer to the community and its cleaning is expected to be louder than that of Basin 2, we conducted most of our sound modeling on the cleaning of Basin 1.

The following figures (4-9) show the results of the sound modeling for different scenarios without any acoustical treatments. The color-coded noise contours are shown for the areas outside of the fence line. The effects of treatments are discussed and shown in the next section. Different sound levels are shown with different colors. Also shown in the figures are two community locations with black and white circles that represent the first row of houses west of the facility (R1) and the 3rd row of houses west of the facility (R3).

The results of the sound modeling of different scenarios and treatments at these locations are summarized in a table in the next section of this report.

Figure 4. Normal Operating Conditions

Figure 5. Normal Operating Conditions with Lime Blower on Truck

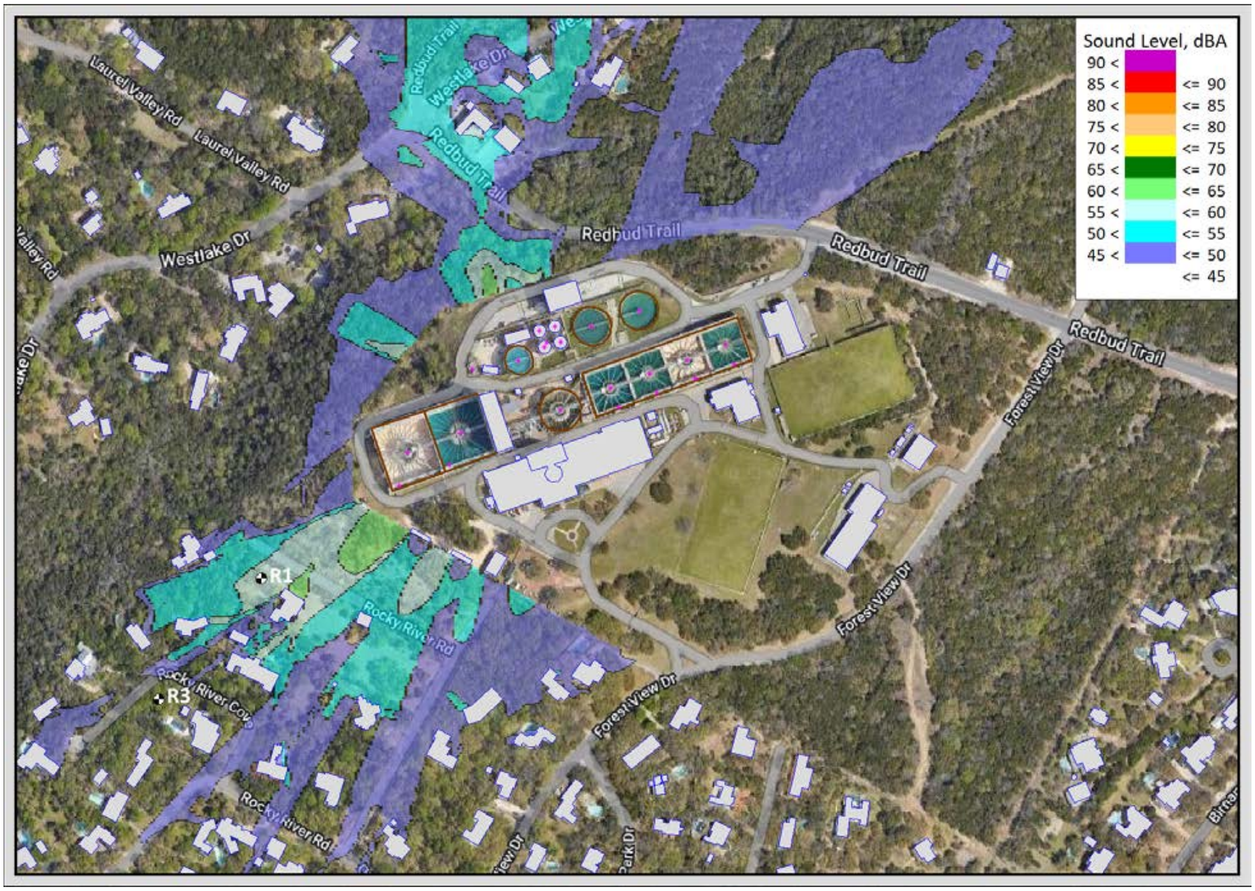


Figure 6. Normal Operating Conditions with Lime Blower Inside Building

Figure 7. Basin Cleaning of Basin 1

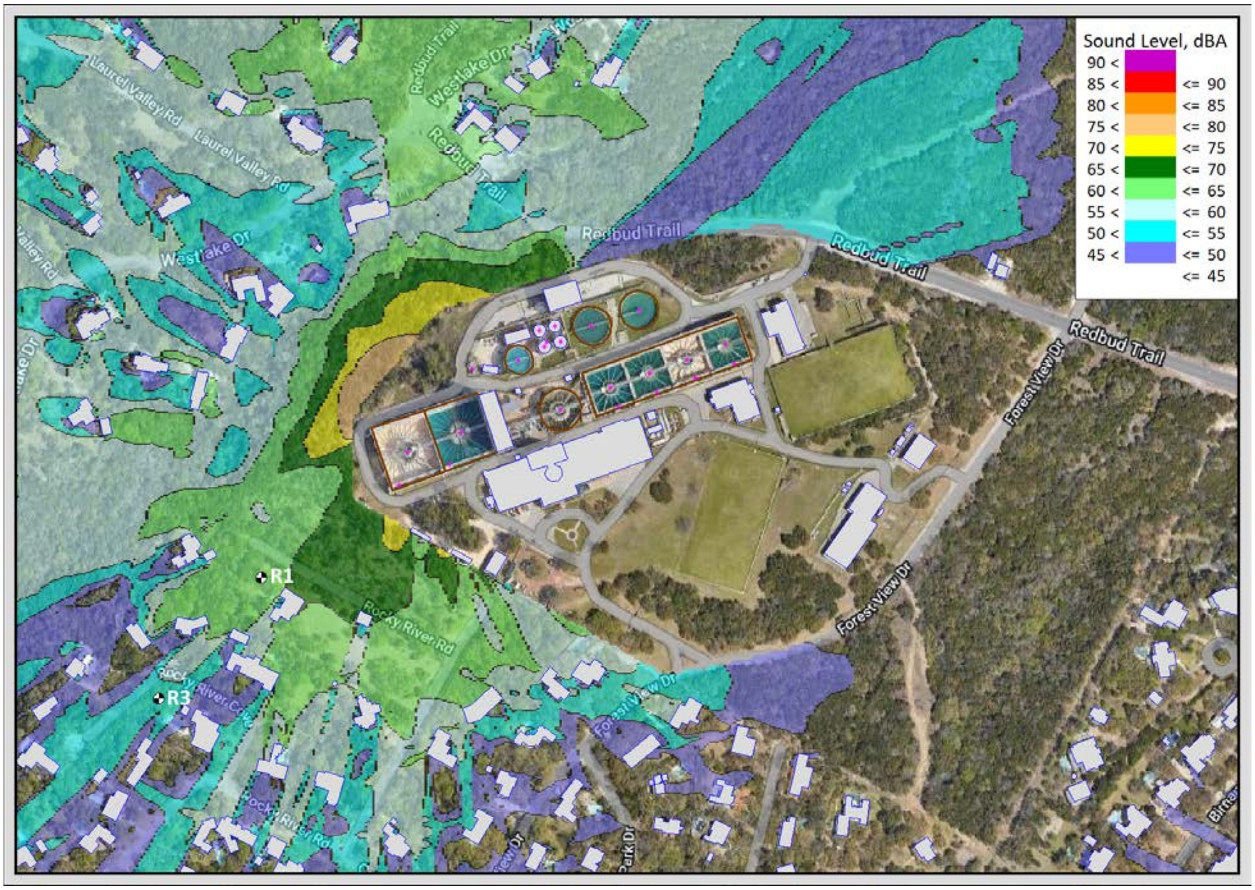


Figure 8. Basin Cleaning of Basin 2

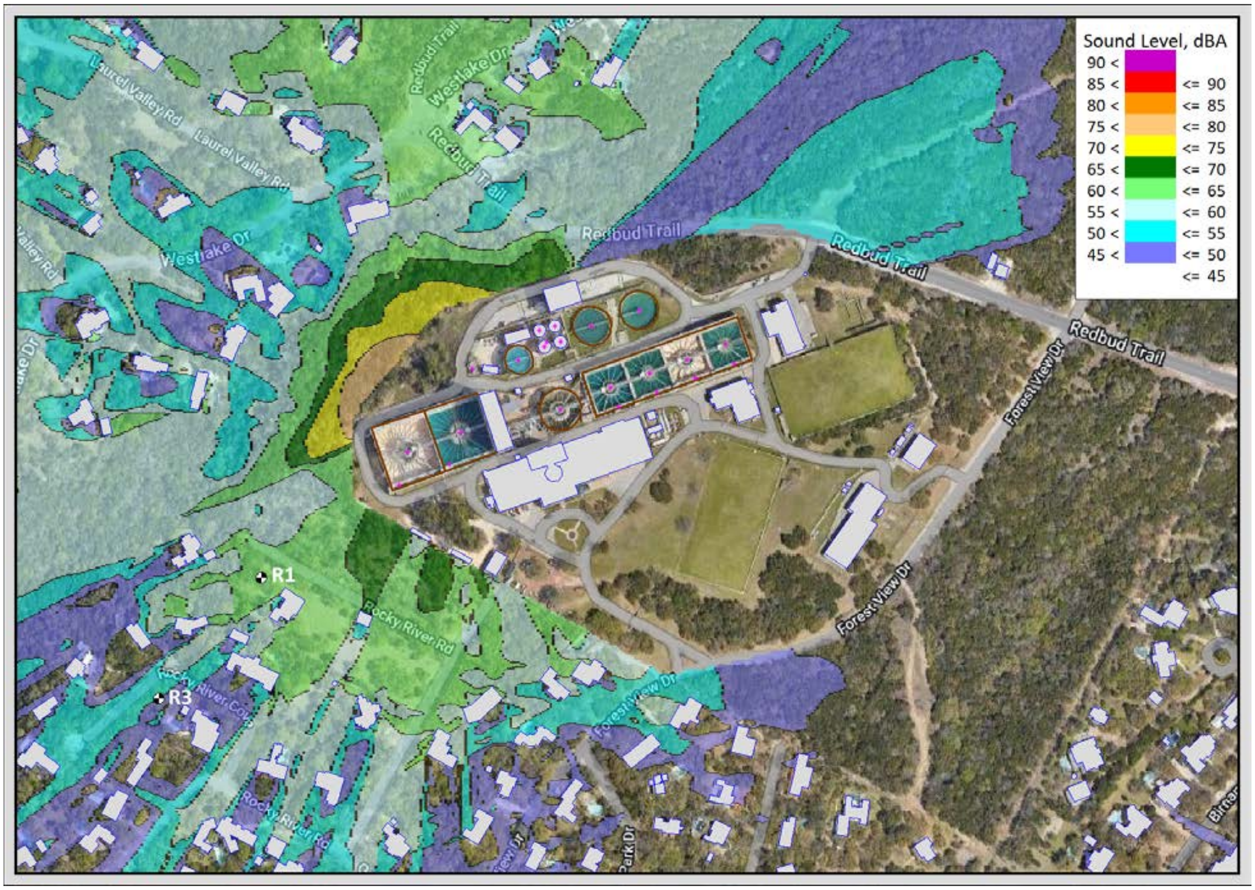
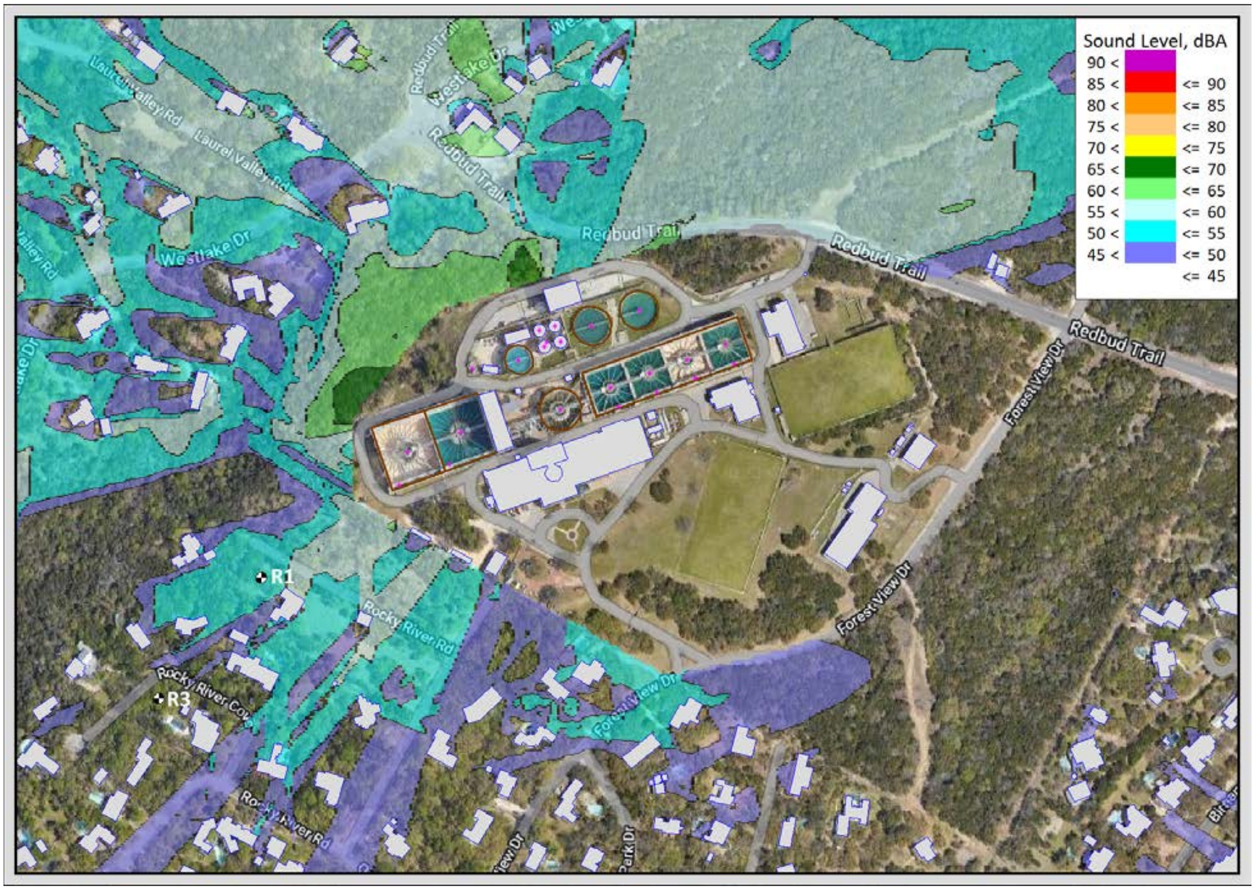


Figure 9. Basin Cleaning of Basin 4



6 NOISE-CONTROL TREATMENTS

For the different scenarios discussed in the previous section, we modeled different options for noise control. These consisted primarily of noise barriers. The variables that affect the amount of reduction provided by a noise barrier are:

- The location of the barrier. It will be most effective when close to the sound source or the sound receiver and least effective if it is near the middle between these.
- The height of the barrier. A barrier will reduce the sound only if it blocks the direct line of sight (and sound) from the sound source to the sound receiver. Some sound will still diffract over the top of the barrier, but the higher the barrier, the greater the sound reduction.
- The frequency of the sound. Barriers are more effective at reducing high-frequency sounds than low-frequency sounds.
- The barrier material. A very lightweight barrier or a barrier with significant gaps in it would allow sound through the barrier. However, in most cases with a reasonably solid barrier (steel, masonry, overlapping wood boards, etc.), the limitation of the barrier is the sound curving over the top, not the sound going through the wall.
- Sound absorption/reflection. A solid wall will reflect sound much like a mirror reflects light. To prevent reflected sound from potentially increasing sound levels, sound-absorptive materials can be used to absorb the sound that is incident on the barrier, preventing any significant sound reflections.

The cost of noise barriers increases at a greater rate than the height of the wall. This is because the vertical supports and foundation of a tall wall must be strong enough to handle substantial wind loads. Adding a noise barrier on top of an existing structure (like the basins) can also be complicated due to the added loads.

The figures in this section do not present color-coded sound levels like those in the previous section. Instead, they show the effect of the modeled treatment. For example, to show the effect of a wall, the sound levels with the wall are compared to the sound levels without the wall. A negative value indicates a sound reduction from the treatment. A positive number indicates an increase in sound levels (such as from a sound reflection off the wall). Where the increase or decrease was less than 1 dBA, we didn't plot a color overlay because that amount of change is not normally perceptible.

The following lists the labels that we have for the different treatment options that were modeled:

- B = barrier on top of Basin 1 and 2 at south and west edges of the basins ("L" shaped). This barrier is about 450 ft long total and was modeled at 6', 10', or 16' tall.
- D = barrier between the Ullrich perimeter driveway and the fence west of Basin 1. This barrier is about 140 ft long and 20' tall.
- F = barrier along west fence line just west of Basin 1. This barrier is about 550 ft long and was modeled at 12' or 20' tall.
- R = barrier near the residences constructed within the buffer zone about 50 ft east of the long driveway to 808 Rocky River Rd. This barrier is about 750 ft long and was modeled at 12', 20', or 25' tall.
- L = barrier at grade on the lawn area just south of Basins 1 and 2 extending between the roadway and the wall of Basins 1 and 2. This barrier is about 100 ft long and 20' tall.
- BB = building blower treatment (instead of using truck-mounted blower)
- QBB = Quiet Building Blower (better silencer on building blower)
- LB Abs = Sound absorption on the west facade of the Lime Building (near Basin 2)

Different height barriers were modeled at the different barrier locations with the barrier height in feet indicated by the number after the barrier letter. For example, “F20” means a 20-ft tall wall built along the fence line.

The locations for the optional noise barriers are shown in Figure 10 along with the modeling locations representing the 1st row of houses (R1) and the 3rd row of houses (R3).

Figure 10. Optional Locations Considered for Noise Barriers

The following table summarizes the effects of the different treatment options at the two community locations. A negative value indicates a reduction in the sound level.

Table 2. Summary of Treatment Effects

Operating Scenario	Treatment	Sound Level & Effect of treatment, dBA	
		Location R1	Location R3
Normal operations	*None*	***34.8***	***24.5***
	B6	-2.4	-2.0
	B6 + D20	-3.1	-2.0
	B6 + L20	-2.4	-2.1
	B10	-3.5	-3.3
	B16	-4.0	-3.7
	D20	-2.0	-0.1
	F12	0	0
	F20	-2.0	-0.1
	R12	-1.9	0
	R20	-3.3	-0.1
Truck-mounted Lime Blower	*None*	***56.0***	***43.8***
	L20	-7.6	-2.8
	D20	-6.2	-1.3
	F12	-4.3	0
	F20	-5.7	-1.1
	R20	-6.1	-0.1
	BB	-11.4	-12
	QBB	-17.5	-18
Cleaning of Basin 1	*None*	***63.3***	***52.5***
	B6	-3.7	-4.2
	B10	-5.0	-5.5
	B16	-5.2	-4.8
	D16	-0.8	-0.2
	B6 + D20	-5.5	-4.9
	B10 + D20	-7.9	-6.4
	B10 + D20 + LB Abs.	-7.9	-6.4
	B6 + L20	-6.4	-5.9
	B10 + L20	-9.4	-8.2
	F12	-0.5	0
	F20	-2.8	-0.6
	R12	-1.0	0
	R20	-6.0	-1.4
	R25	-7.3	-2.2
Cleaning of Basin 2	*None*	***61.2***	***48.5***
	B6	-1.4	-0.7
	B10	-1.5	-0.9
	B16	-2.5	-1.3
	B6 + L20	-4.1	-2.7
	B10 + L20	-4.2	-3.2
	B6 + D20	-3.6	-1.4
	B10 + D20	-3.6	-1.7
	B10 + D20 + LB Abs	-4.9	-2.4
	F20	-2.6	-0.4
	R20	-5.0	-0.2

Here is a summary of the best treatments for different operations:

Normal Operations: Since the major sound source during normal operations is the waterfall noise from Basins 1 and 2, the best treatment is the barrier at the edges of Basins 1 and 2 (Barrier B).

Lime Loading: Since the blower used during lime loading is the dominant sound source, the best treatments are those that directly reduce this noise. Using the blower within the Lime Building reduces sound levels by 10+ dBA. Using this interior blower with a better silencer would reduce sound levels by an additional 6 dBA (depending on the silencer). Barriers at locations L, D, F, and R all are effective at reducing the blower noise at the first row of residences (R1) but have little effect further into the neighborhood (R3).

Cleaning of Basins 1 and 2: The dominant sound sources during Basin 1 cleaning are the spraying within the basin and the vacuum truck. The barriers around the basin are best at reducing the spraying noise, and Barriers L and D are best at reducing the noise from the vacuum truck. The barrier nearest the residences at location R is effective at reducing the blower noise at the first row of residences (R1) but has little effect further into the neighborhood (R3). Barrier B is more effective at reducing noise from the Basin 1 cleaning than Basin 2 cleaning (because it is closer to this noise source).

Here is a summary of the effectiveness of the different treatments:

Lime Blower Treatments: The blower treatments (using the blower within the building and improving the silencer on this blower) are very effective at reducing noise from the lime blowing operations.

Basin Barrier B: This barrier is effective at reducing noise from the spray cleaning of the basins and the basin waterfalls but has no effect on most other noises. Taller barriers are better than lower barriers, but even a 6-ft tall barrier provides good reduction of the spraying noise. If an additional treatment (Barrier L or D) is used to reduce the vacuum noise, a 10-ft wall for the Basin Barrier is 2-to-3 dBA more effective than a 6-ft wall at reducing noise from Basin 1 cleaning. This barrier is more effective with the cleaning of Basin 1 than the cleaning of Basin 2 (which is further away from the barrier).

Lime Building West Façade Sound Absorption: This treatment reduces sound reflections off the building and has a minor benefit (about 1 dBA) during the cleaning of Basin 2 but has no benefit for any other noises including the cleaning of Basin 1.

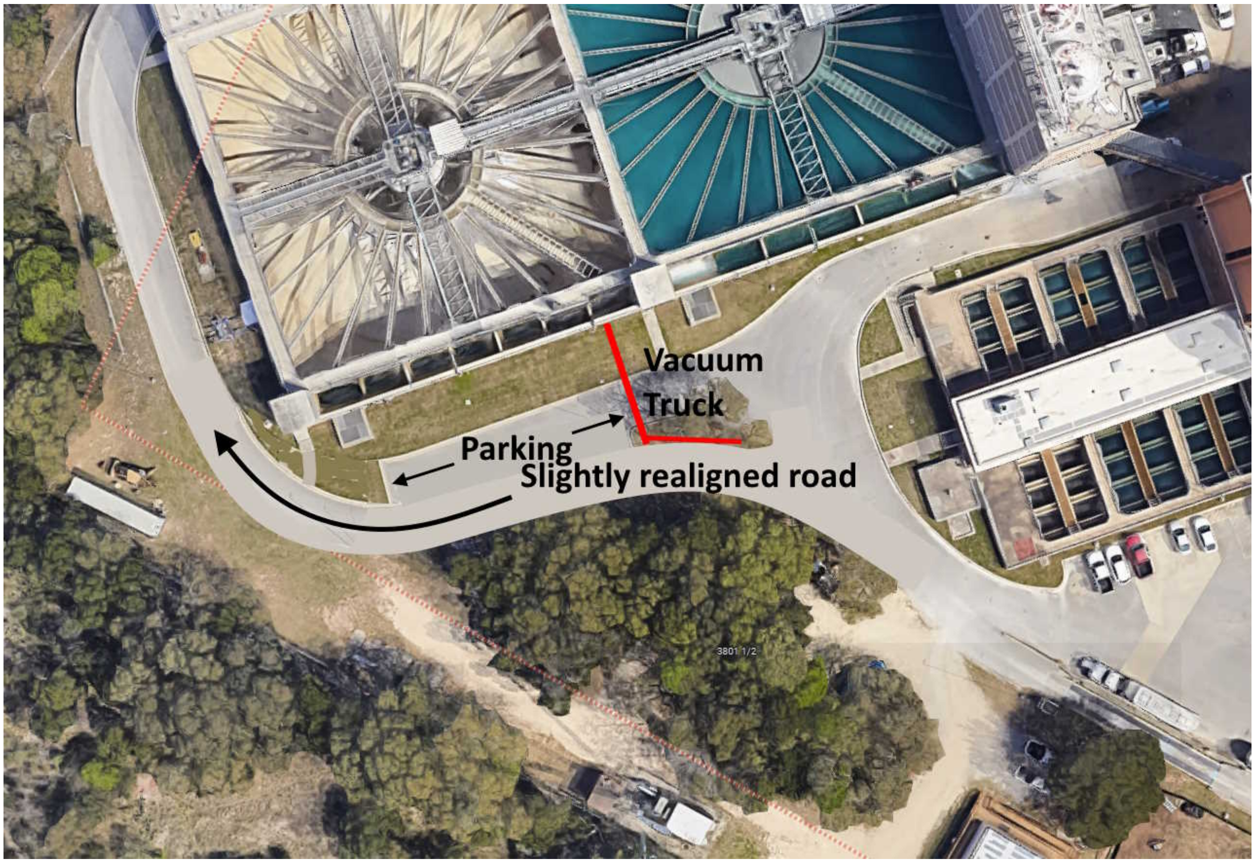
Fenceline Barrier F: This barrier is moderately effective at reducing some noises at the first row of houses but has very little benefit further into the neighborhood.

Barrier R nearest Residences: This barrier within the buffer area is moderately effective at reducing some noises at the first row of houses but has very little benefit further into the neighborhood. A taller barrier (20 ft) is better than a lower barrier (12 ft), but the benefits do not extend far into the neighborhood. Increasing the wall height from 20 to 25 ft has about a 1 dBA benefit.

Barrer D by Ullrich Perimeter Driveway: This barrier has some benefit for the lime blower and the vacuum truck. It will also provide benefit for any other noises propagating down the alley within the treatment plant such as noise from trucks and the basin cleaning of Basin 4.

Barrer L by Lawn and Perimeter Driveway: This barrier reduces noise from the lime blower and the vacuum truck. Like Barrier D, it will also provide benefit for any other noises propagating down the alley within the treatment plant such as noise from trucks and the basin cleaning of Basin 4. Because the current lawn area between Basins 1 and 2 and the Ullrich driveway is narrow, this treatment is most effective if the driveway is relocated further from the basins to allow room for a longer barrier as shown in Figure 11.

Figure 11. Barrier L with Ullrich Driveway Relocated



Figures 12 through 18 present the benefits of the treatment options that are most effective. These are not noise contours like the earlier figures but are color coded to show the effect of the difference in sound levels with an added or different treatment. No coloring of the map indicates no effect (an increase or decrease of less than 1 dBA, which is normally not noticeable).

Figure 12. Normal Operations: Effect of Treatment B10

The above figure shows the benefit of Barriers B10 during normal operations (primarily reducing waterfall noise).

Figure 13. Cleaning of Basin 1: Treatment B10 & D20

The above figure shows the benefit of Barriers B10 (to reduce the spraying noise) and D20 (to reduce the vacuum truck noise) during Basin 1 cleaning.

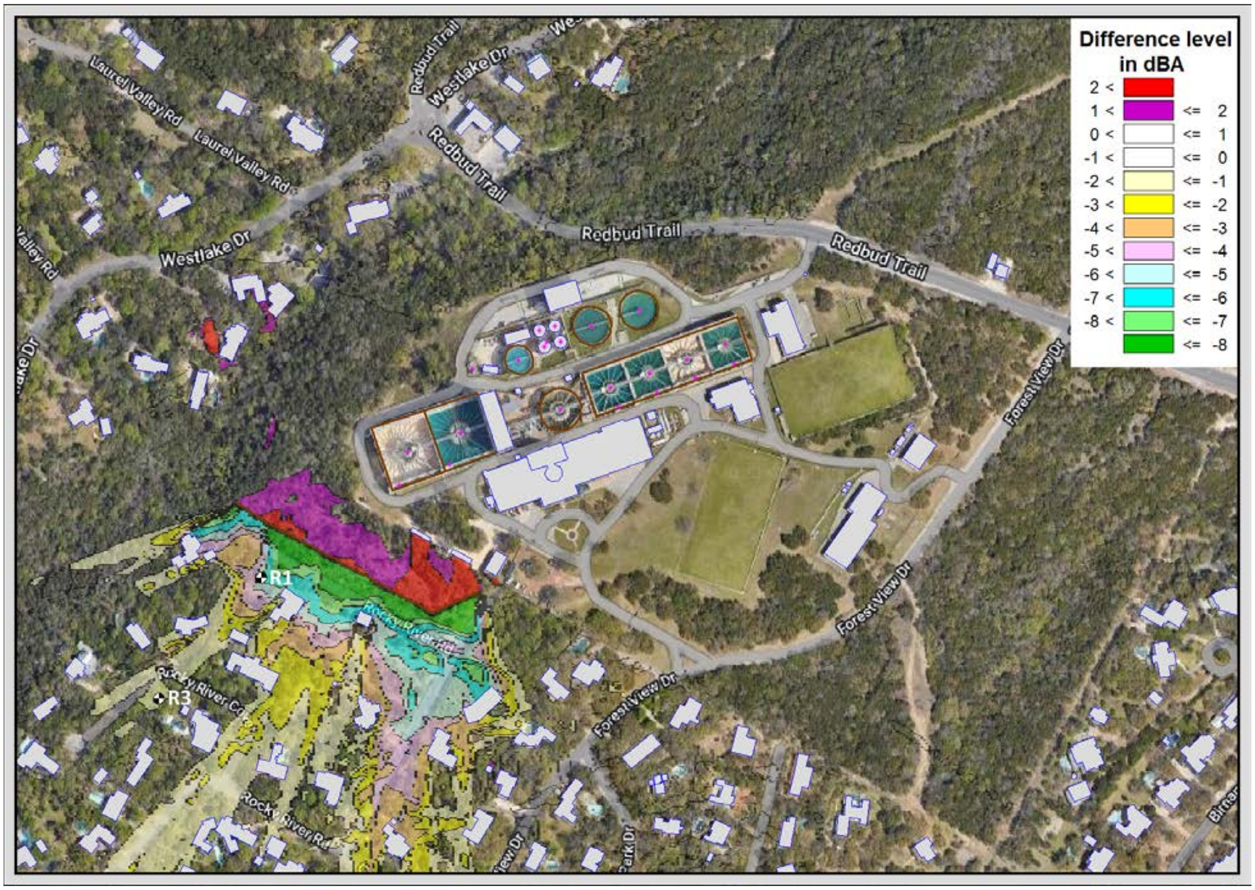
Figure 14. Cleaning of Basin 1 with D20: Treatment B6 vs B10

The above figure shows the additional benefit when the height of the barrier at the edge of Basins 1 and 2 is increased from 6 ft to 10 ft during Basin 1 cleaning, assuming that Barrier D20 is also constructed to reduce noise from the vacuum truck.

Figure 15. Cleaning of Basin 1 with B10: D20 vs L20

The above figure shows that during Basin 1 cleaning with treatment B10 on the basins, Barrier L20 (right next to the vacuum truck) is 2- to-3 dBA more effective than D20, which is closer to the fence line (further from the noise sources).

Figure 16. Cleaning of Basin 1: Effect of R20



The above figure shows that during Basin 1 cleaning, Barrier R20 in the Buffer Zone is effective at reducing noise at the first row of residences but is not as effective further into the neighborhood.

7 FUTURE PLANS

The feasibility of the modeled treatments will be evaluated along with their effectiveness to determine how to proceed.

8 SUMMARY

Collaboration in Science and Technology Inc. (CSTI) was retained by Kennedy/Jenks on behalf of the City of Austin to conduct a noise study of the Ullrich Water Treatment Plant (WTP) located in Austin, TX. Sound levels were measured in November 2022 and then modeled to evaluate the effectiveness of different noise-control treatments during normal and intermittent operations.

The most effective treatment is a noise barrier around the edge of Basins 1 and 2 (Barrier B in our modeling). This reduces waterfall noise during normal operations and the noise from basin cleaning within Basins 1 and 2. A 6-ft tall wall is somewhat effective. A 10-ft tall wall is more effective. A 12-ft wall (not modeled) would be slightly more effective than a 10-ft tall wall, but there may be practical issues with building a wall any taller than 12 ft.

To reduce the noise of the vacuum truck used during basin cleaning, a barrier is needed between the vacuum truck and the community. Our modeled Barriers L and D are both effective at reducing the noise from the vacuum truck and also reduce some noise from the lime blower and any other sound sources propagated down the alley within the facility.

Barrier L is somewhat more effective than Barrier D, but it may be less feasible as it would require a slight realignment of the driveway around the facility.

Barrier F along the fence line and Barrier R in the buffer area nearest the residences have little benefit beyond the first row of houses.

To reduce the noise from the lime-blowing operation, the best option is to use the blower within the building. This noise could be further reduced with a better silencer for this blower.

The barriers work well as long as they have no major gaps and the material is solid. Steel, masonry, overlapping wood boards, cement board (Hardiplank), noise curtains, etc., are all fine and essentially equivalent because the limitation is the sound curving over the top of the barrier, not the sound going through it.

A solid noise barrier will reflect sound back towards the sound source. There is a potential for slight increases in the sound level (1 to 2 dBA) on the sound-source side of the barrier. Our modeling did not show any significant increases beyond the property line (less than 1 dBA) with solid sound-reflective noise barriers. If the surface of the barrier facing the sound source is sound-absorptive (an NRC rating of at least 0.70), there will be no significant sound reflections or sound increases anywhere due to sound reflections off the barrier.

Appendix II: Opinion of Probable Construction Costs

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier B6- 450ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

[x] **Conceptual**
[ ] **Preliminary (w/o plans)**
[ ] **Design Development @** ________ **% Complete**
[ ] **Construction**
[ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	6 Foot Wall Panels (Galvanized 22 ga)	2,700	sf	$24.50	66,150	$10.50	28,350			$94,500
2	Galv. W-section Posts	45	ea	$360.00	16,200	$240.00	10,800			$27,000
3	Anchor Bolts and Baseplate	45	ea	$120.00	5,400	$80.00	3,600			$9,000
	Subtotals				$87,750		$42,750			$130,500
	Division 1 Costs	@	10%		$8,775		$4,275			$13,050
	Subtotals				$96,525		$47,025			$143,550
	Taxes - Materials Costs	@								
	Subtotals				$96,525		$47,025			$143,550
	Taxes - Labor Costs	@								
	Subtotals				$96,525		$47,025			$143,550
	Contractor Markup for Sub	@	12%							
	Subtotals				$96,525		$47,025			$143,550
	Contractor OH&P	@	15%		$14,479		$7,054			$21,533
	Subtotals				$111,004		$54,079			$165,083
	Estimate Contingency	@	30%							$49,525
	Subtotals									$214,607
	Escalate to Midpoint of Construct	@	2%							$2,146
	Estimated Bid Cost									$216,753
	Total Estimate									$217,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$325,500	**$217,000**	**$151,900**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier B10- 450ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

[x] **Conceptual**
[ ] **Preliminary (w/o plans)**
[ ] **Design Development @** ________ **% Complete**
[ ] **Construction**
[ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	10 Foot Wall Panels (Galvanized 22 ga)	4,500	sf	$24.50	110,250	$10.50	47,250			$157,500
2	Galv. W-section Posts	45	ea	$480.00	21,600	$320.00	14,400			$36,000
3	Anchor Bolts and Baseplate	45	ea	$180.00	8,100	$120.00	5,400			$13,500
	Subtotals				$139,950		$67,050			$207,000
	Division 1 Costs	@	10%		$13,995		$6,705			$20,700
	Subtotals				$153,945		$73,755			$227,700
	Taxes - Materials Costs	@								
	Subtotals				$153,945		$73,755			$227,700
	Taxes - Labor Costs	@								
	Subtotals				$153,945		$73,755			$227,700
	Contractor Markup for Sub	@	12%							
	Subtotals				$153,945		$73,755			$227,700
	Contractor OH&P	@	15%		$23,092		$11,063			$34,155
	Subtotals				$177,037		$84,818			$261,855
	Estimate Contingency	@	30%							$78,557
	Subtotals									$340,412
	Escalate to Midpoint of Construct	@	2%							$3,404
	Estimated Bid Cost									$343,816
	Total Estimate									$344,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$516,000	**$344,000**	**$240,800**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier B6- 450ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

[x] **Conceptual**
[ ] **Preliminary (w/o plans)**
[ ] **Design Development @** ________ **% Complete**
[ ] **Construction**
[ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	6 Foot Wall Panels (Galvanized 22 ga)	2,700	sf	$24.50	66,150	$10.50	28,350			$94,500
2	Galv. W-section Posts	45	ea	$360.00	16,200	$240.00	10,800			$27,000
3	Anchor Bolts and Baseplate	45	ea	$120.00	5,400	$80.00	3,600			$9,000
	Subtotals				$87,750		$42,750			$130,500
	Division 1 Costs	@	10%		$8,775		$4,275			$13,050
	Subtotals				$96,525		$47,025			$143,550
	Taxes - Materials Costs	@								
	Subtotals				$96,525		$47,025			$143,550
	Taxes - Labor Costs	@								
	Subtotals				$96,525		$47,025			$143,550
	Contractor Markup for Sub	@	12%							
	Subtotals				$96,525		$47,025			$143,550
	Contractor OH&P	@	15%		$14,479		$7,054			$21,533
	Subtotals				$111,004		$54,079			$165,083
	Estimate Contingency	@	30%							$49,525
	Subtotals									$214,607
	Escalate to Midpoint of Construct	@	2%							$2,146
	Estimated Bid Cost									$216,753
	Total Estimate									$217,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$325,500	**$217,000**	**$151,900**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier D16 - 140ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

[x] **Conceptual**
[ ] **Preliminary (w/o plans)**
[ ] **Design Development @** ________ **% Complete**
[ ] **Construction**
[ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	16 Foot Wall Panels	2,700	sf	$44.40	119,880	$29.60	79,920			$199,800
2	Post and Drilled Shaft 48"	7	ea	$1,466.40	10,265	$977.60	6,843			$17,108
3	4" Riprap (Conc) Base	13	cy	$390.00	5,070	$260.00	3,380			$8,450
	Subtotals				$135,215		$90,143			$225,358
	Division 1 Costs	@	10%		$13,521		$9,014			$22,536
	Subtotals				$148,736		$99,158			$247,894
	Taxes - Materials Costs	@								
	Subtotals				$148,736		$99,158			$247,894
	Taxes - Labor Costs	@								
	Subtotals				$148,736		$99,158			$247,894
	Contractor Markup for Sub	@	12%							
	Subtotals				$148,736		$99,158			$247,894
	Contractor OH&P	@	15%		$22,310		$14,874			$37,184
	Subtotals				$171,047		$114,031			$285,078
	Estimate Contingency	@	30%							$85,523
	Subtotals									$370,601
	Escalate to Midpoint of Construct	@	2%							$3,706
	Estimated Bid Cost									$374,307
	Total Estimate									$375,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$562,500	**$375,000**	**$262,500**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Alternative **Sound Barrier F12 - 550ft**

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

- [x] **Conceptual**
- [ ] **Preliminary (w/o plans)**
- [ ] **Design Development @** ______ **% Complete**
- [ ] **Construction**
- [ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	12 Foot Wall Panels	6,600	sf	$44.40	293,040	$29.60	195,360			$488,400
2	Post and Drilled Shaft 42"	28	ea	$1,164.00	32,592	$776.00	21,728			$54,320
3	4" Riprap (Conc) Base	48	cy	$390.00	18,720	$260.00	12,480			$31,200
	Subtotals				$344,352		$229,568			$573,920
	Division 1 Costs	@	10%		$34,435		$22,957			$57,392
	Subtotals				$378,787		$252,525			$631,312
	Taxes - Materials Costs	@								
	Subtotals				$378,787		$252,525			$631,312
	Taxes - Labor Costs	@								
	Subtotals				$378,787		$252,525			$631,312
	Contractor Markup for Sub	@	12%							
	Subtotals				$378,787		$252,525			$631,312
	Contractor OH&P	@	15%		$56,818		$37,879			$94,697
	Subtotals				$435,605		$290,404			$726,009
	Estimate Contingency	@	30%							$217,803
	Subtotals									$943,811
	Escalate to Midpoint of Construct	@	2%							$9,438
	Estimated Bid Cost									$953,250
	Total Estimate									$954,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$1,431,000	**$954,000**	**$667,800**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier R20 - 750ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

- [x] **Conceptual**
- [ ] **Preliminary (w/o plans)**
- [ ] **Design Development @** ______ **% Complete**
- [ ] **Construction**
- [ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	20 Foot Wall Panels	15,000	sf	$44.40	666,000	$29.60	444,000			$1,110,000
2	Post and Drilled Shaft 48"	38	ea	$1,466.40	55,723	$977.60	37,149			$92,872
3	4" Riprap (Conc) Base	65	cy	$390.00	25,350	$260.00	16,900			$42,250
	Subtotals				$747,073		$498,049			$1,245,122
	Division 1 Costs	@	10%		$74,707		$49,805			$124,512
	Subtotals				$821,781		$547,854			$1,369,634
	Taxes - Materials Costs	@								
	Subtotals				$821,781		$547,854			$1,369,634
	Taxes - Labor Costs	@								
	Subtotals				$821,781		$547,854			$1,369,634
	Contractor Markup for Sub	@	12%							
	Subtotals				$821,781		$547,854			$1,369,634
	Contractor OH&P	@	15%		$123,267		$82,178			$205,445
	Subtotals				$945,048		$630,032			$1,575,079
	Estimate Contingency	@	30%							$472,524
	Subtotals									$2,047,603
	Escalate to Midpoint of Construct	@	2%							$20,476
	Estimated Bid Cost									$2,068,079
	Total Estimate									$2,069,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$3,103,500	**$2,069,000**	**$1,448,300**

OPINION OF PROBABLE CONSTRUCTION COST — **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier R12 - 750ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

☒ **Conceptual** ☐ **Construction**
☐ **Preliminary (w/o plans)** ☐ **Change Order**
☐ **Design Development @** ________ **% Complete**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	12 Foot Wall Panels	9,000	sf	$44.40	399,600	$29.60	266,400			$666,000
2	Post and Drilled Shaft 42"	38	ea	$1,164.00	44,232	$776.00	29,488			$73,720
3	4" Riprap (Conc) Base	65	cy	$390.00	25,350	$260.00	16,900			$42,250
	Subtotals				$469,182		$312,788			$781,970
	Division 1 Costs	@	10%		$46,918		$31,279			$78,197
	Subtotals				$516,100		$344,067			$860,167
	Taxes - Materials Costs	@								
	Subtotals				$516,100		$344,067			$860,167
	Taxes - Labor Costs	@								
	Subtotals				$516,100		$344,067			$860,167
	Contractor Markup for Sub	@	12%							
	Subtotals				$516,100		$344,067			$860,167
	Contractor OH&P	@	15%		$77,415		$51,610			$129,025
	Subtotals				$593,515		$395,677			$989,192
	Estimate Contingency	@	30%							$296,758
	Subtotals									$1,285,950
	Escalate to Midpoint of Construct	@	2%							$12,859
	Estimated Bid Cost									$1,298,809
	Total Estimate									$1,299,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$1,948,500	**$1,299,000**	**$909,300**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier F20 - 550ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

[x] **Conceptual**
[ ] **Preliminary (w/o plans)**
[ ] **Design Development @** ________ **% Complete**
[ ] **Construction**
[ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	20 Foot Wall Panels	11,000	sf	$44.40	488,400	$29.60	325,600			$814,000
2	Post and Drilled Shaft 48"	28	ea	$1,466.40	41,059	$977.60	27,373			$68,432
3	4" Riprap (Conc) Base	48	cy	$390.00	18,720	$260.00	12,480			$31,200
	Subtotals				$548,179		$365,453			$913,632
	Division 1 Costs	@	10%		$54,818		$36,545			$91,363
	Subtotals				$602,997		$401,998			$1,004,995
	Taxes - Materials Costs	@								
	Subtotals				$602,997		$401,998			$1,004,995
	Taxes - Labor Costs	@								
	Subtotals				$602,997		$401,998			$1,004,995
	Contractor Markup for Sub	@	12%							
	Subtotals				$602,997		$401,998			$1,004,995
	Contractor OH&P	@	15%		$90,450		$60,300			$150,749
	Subtotals				$693,447		$462,298			$1,155,744
	Estimate Contingency	@	30%							$346,723
	Subtotals									$1,502,468
	Escalate to Midpoint of Construct	@	2%							$15,025
	Estimated Bid Cost									$1,517,493
	Total Estimate									$1,518,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$2,277,000	**$1,518,000**	**$1,062,600**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier R25 - 750ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

- [x] **Conceptual**
- [ ] **Preliminary (w/o plans)**
- [ ] **Design Development @** ________ **% Complete**
- [ ] **Construction**
- [ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	25 Foot Wall Panels	18,750	sf	$44.40	832,500	$29.60	555,000			$1,387,500
2	Post and Drilled Shaft 48"	38	ea	$1,466.40	55,723	$977.60	37,149			$92,872
3	4" Riprap (Conc) Base	65	cy	$390.00	25,350	$260.00	16,900			$42,250
	Subtotals				$913,573		$609,049			$1,522,622
	Division 1 Costs	@	10%		$91,357		$60,905			$152,262
	Subtotals				$1,004,931		$669,954			$1,674,884
	Taxes - Materials Costs	@								
	Subtotals				$1,004,931		$669,954			$1,674,884
	Taxes - Labor Costs	@								
	Subtotals				$1,004,931		$669,954			$1,674,884
	Contractor Markup for Sub	@	12%							
	Subtotals				$1,004,931		$669,954			$1,674,884
	Contractor OH&P	@	15%		$150,740		$100,493			$251,233
	Subtotals				$1,155,670		$770,447			$1,926,117
	Estimate Contingency	@	30%							$577,835
	Subtotals									$2,503,952
	Escalate to Midpoint of Construct	@	2%							$25,040
	Estimated Bid Cost									$2,528,991
	Total Estimate									$2,529,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$3,793,500	**$2,529,000**	**$1,770,300**

OPINION OF PROBABLE CONSTRUCTION COST **KENNEDY/JENKS CONSULTANTS, INC.**

Project: Ullrich Water Treatment Noise Abatement

Alternative **Sound Barrier L20 - 100ft**

Prepared By: KJ
Date Prepared: 1-Aug-23
KJ Proj. No. 2245006

Current at ENR
Escalated to ENR
Months to Midpoint of Construct 6

[x] **Conceptual**
[ ] **Preliminary (w/o plans)**
[ ] **Design Development @** ________ **% Complete**
[ ] **Construction**
[ ] **Change Order**

No.	Description	Qty	Units	Materials $/Unit	Materials Total	Installation $/Unit	Installation Total	Sub-contractor $/Unit	Sub-contractor Total	Total
1	20 Foot Wall Panels	2,000	sf	$44.40	88,800	$29.60	59,200			$148,000
2	Post and Drilled Shaft 48"	5	ea	$1,466.40	7,332	$977.60	4,888			$12,220
3	4" Riprap (Conc) Base	9	cy	$390.00	3,510	$260.00	2,340			$5,850
	Subtotals				$99,642		$66,428			$166,070
	Division 1 Costs	@	10%		$9,964		$6,643			$16,607
	Subtotals				$109,606		$73,071			$182,677
	Taxes - Materials Costs	@								
	Subtotals				$109,606		$73,071			$182,677
	Taxes - Labor Costs	@								
	Subtotals				$109,606		$73,071			$182,677
	Contractor Markup for Sub	@	12%							
	Subtotals				$109,606		$73,071			$182,677
	Contractor OH&P	@	15%		$16,441		$10,961			$27,402
	Subtotals				$126,047		$84,031			$210,079
	Estimate Contingency	@	30%							$63,024
	Subtotals									$273,102
	Escalate to Midpoint of Construct	@	2%							$2,731
	Estimated Bid Cost									$275,833
	Total Estimate									$276,000

Estimate Accuracy	
+50%	-30%

Estimated Range of Probable Cost		
+50%	Total Est.	-30%
$414,000	**$276,000**	**$193,200**