Appendix C
Alternative Mitigation:
Further Details

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

This appendix includes further details about alternative noise mitigation measures that might be considered along the Pima Freeway corridor in Scottsdale.

Any one mitigation measure may not be appropriate for every neighborhood along the Freeway. Further, some neighborhoods might benefit from a combination of mitigation measures. Specific recommendations for specific neighborhoods appear above, in the main body of this report. This appendix, itself, provides further detail about mitigation alternatives—detail that is general in nature, that applies to all neighborhoods where that alternative is recommended above.

More specifically, for each mitigation alternative, this appendix includes information about:

- Achievable noise reductions
- General costs
- General location of benefited residences
- Benefit/cost ratios
- Life cycles
- Maintenance
- General neighborhood acceptance
- Detrimental environmental impacts
- Social considerations
- Aesthetics
- Safety considerations

CHAPTER 1: ABSORPTIVE FACINGS ON NOISE BARRIERS

1.1 Achievable noise reduction

Absorptive barrier facing is generally considered as a mitigation option where a barrier might otherwise reflect sound to neighbors on the opposite side of the highway. In these situations, it can reduce sound levels up to 3 decibels, by essentially eliminating the reflected sound. For this purpose, some states are recommending absorptive materials for all future noise barrier programs.

In addition, absorptive barrier facings very slightly reduce sound behind the barrier. Some studies have shown improvements of 1 decibel or more in the single-barrier insertion loss for barriers with efficient absorptive surfaces.[1]

The FHWA Traffic Noise Model (TNM) accounts for this in its calculations. However, TNM computations along the Pima Freeway indicate that this reduction would average less than 0.2 decibels. For this reason, absorptive facings are not recommended.

Although sound absorption is not recommended along the Pima Freeway, this portion of the appendix describes such absorption, for possible future use elsewhere within the City of Scottsdale.

Available absorptive facings

A list of available absorptive facings was compiled for this study, using information from *Evaluation of Low Cost Highway Noise Barriers* (1997)[2], *Compendium of General Information on Highway Noise Barriers* (1997)[3], issues of *The Wall Journal* (1996-2001)[4], manufacturers' literature, and Internet searches.

Each manufacturer and/or licensee was contacted by telephone to provide the most current cost and performance information for new barrier and/or retrofit application. Values for Noise Reduction Coefficient (NRC) and Sound Transmission Class (STC), which vary by material thickness, are specified with thickness if published by the manufacturer.

The information in Tables 1 and 2 is based on current 2003 data acquired directly from each of the listed manufacturers and/or licensees. Acoustical terms are defined in the section following the tables.

Absorptive Material Standards and Criteria

The Noise Reduction Coefficient (NRC) provides a measure of the effectiveness of a material in absorbing incident sound. The value is equivalent to the fraction of incident sound absorbed, ranging

---

[1] "Technical Assessment of the Effectiveness of Noise Walls, Final Report," International Institute of Noise Control Engineering Publication 99-1, *Noise/News International*, Vol. 7, No. 3, September 1999.

[2] *Evaluation of Low Cost Highway Noise Barriers*, Pennsylvania Department of Transportation, 1997.

[3] *Compendium of General Information on Highway Noise Barriers*, Harris Miller Miller and Hanson Inc., 1997.

[4] *The Wall Journal.* The Wall Journal and Catseye Services. Bi-monthly,issues from 1996-2001.

from 0.0 to 0.95, and consists of an average of the values measured in the octaves from 250 Hz to 2000 Hz.

An NRC of 0.95 is the highest value supposed to be reported by manufacturers. However, measured values for certain materials may be listed as being greater than 1.0, since the standard testing method over-estimates true sound absorption for some panels. The standard most commonly used for the testing and certification of NRC is provided by the American Society for Testing and Materials under the C-423 Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method.[5]

Table 1 Summary of absorptive treatments for highway noise barriers: new sound wall construction

Manufacturer	Brand	Material	Approximate Costs		Noise Reduction Coefficient (NRC)	Sound Transmission Class (STC)	Contact Info
			$/sq.ft.	$/sq.ft. (installed)			
Durisol Inc.	Durisol	Concrete and Wood Composite	$13	$14-20	0.7 (2 in thick), 0.8 (4 in. thick)	42 (7 in. thick)	Michael Edwards 905-521-0999
Concrete Precast Systems	Whisper Wall (DuBrook)	Concrete and Recycled Rubber	$10-12	$18-20 (concrete posts, panels, foundation)	0.8 (4 in. +4 in. concrete backing)	42 (4 in. + 4 in. concrete backing)	Steve McCowin 703-222-9700
Concrete Solutions, Inc.	Soundsorb	Cement-Based Material (2-3.5 in. thick)	$12-13 (3 in. thick)	$14-17 (3 in. thick)	0.95 (3 in. thick, tested flat)	51 (3 in. + 2.5 in. concrete backing)	O. Boone Bucher 512-327-8481; William Neely (LB Foster - licensee for North America)
Highway & Industrial Noise Solutions	Sound Fighter Systems	Polyethylene with Mineral Wool	$10-16 (panels & steel beams)	$18-21 (panels & steel beams)	1.05 (4.4 in. thick)	33 (4.4 in. thick)	Steve Shough 562-943-2127; Patrick Harrison 318-861-6640
Industrial Acoustics Company, Inc.	Noishield	Steel/Aluminum with Fiberglass	$10	$17	1.05 (5 in. thick)	30-33 (5 in. thick)	John Finnegan 718-430-4571; Jim Harvey 978-443-6525
Empire Acoustical Systems	Silent Screen	Steel with Mineral Wool	$11-15 (2.8 in. thick)	$22-25 (panels, foundation, steel beams)	1.0-1.05 (2.8 in. thick), 0.95-1.15 (4 in. thick)	26-35 (2.8 in. thick), 39-46 (4 in. thick)	Chanelle Garlutzo or Keith McKeown 719-846-2300

---

[5] American Society for Testing and Materials, West Conshohocken, PA, 2001.

Table 2 Summary of absorptive treatments for highway noise barriers: retrofit (for existing sound walls)

Manufacturer	Brand	Material	Approximate Costs		Noise Reduction Coefficient (NRC)	Surface Weight (lb./sq. ft.)	Contact Info
			$/sq.ft.	$/sq.ft. (installed)			
Industrial Acoustics Company, Inc.	Noishield Cladding	Steel/Aluminum with Fiberglass	$7	$9-10	1.00-1.05 (2.5-4 in. thick)	2-3 (steel), 1-2 (aluminum)	John Finnegan 718-430-4571; Jim Harvey 978-443-6525
Pyrok, Inc.	Pyrok Acoustement	Cementitious Spray-on	$12-15 (1.5 in. thick) $1.50 per additional 0.25 in. of thickness		0.7 (1.5 in. thick) 0.8 (1.8 in. thick)	4-5 per in. of thickness (air-dried)	Howard Podolsky 914-777-7070
Concrete Solutions, Inc.	Soundsorb Cladding	Cement-Based Material (2-3.5 in. thick)	$1.50 (3 in. thick)	$8-15 (3 in. thick)	0.95 (3 in. thick, tested flat)	9-13 (dry weight)	O. Boone Bucher 512-327-8481; William Neely (LB Foster - licensee for North America)
Highway & Industrial Noise Solutions	Sound Fighter Systems	Polyethylene with Mineral Wool	$10-16 (panels & steel beams)	$18-21 (panels & steel beams)	1.05 (4.4 in. thick)	5	Steve Shough 562-943-2127; Patrick Harrison 318-861-6640
Durisol Inc.	Durisol Only Panels	Concrete and Wood Composite	$5	$10	0.75 (2 in. thick), 0.85 (3 in. thick)	6-9	Michael Edwards 905-521-0999
Empire Acoustical Systems	M-90	Steel with Mineral Wool	$9-11 (painted, 2.5 in. thick)		1.1	5	Chanelle Garlutzo or Keith McKeown 719-846-2300

No materials with NRC less than 0.7 appear in these two tables. Such materials are not adequate for this application. Further, materials with an NRC of 0.8 or higher are generally recommended. These NRC values ensure that sound will be reduced by 7 decibels or more upon reflection from the absorptive surface. That amount of reduction in reflected energy would produce a net noise reduction (direct sound plus reflected sound) for neighbors across the highway of up to 2-or-3 decibels with such absorptive facings.

The tables also include STC ratings, though they are less relevant here. The Sound Transmission Class (STC) is a rating of the reduction in sound transmitted through a material, in decibels. It is computed from an average of frequency-specific transmission-loss values. The standard most commonly used for the testing and establishment of the STC is provided by the American Society for Testing and Materials under the *E-90 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements*. For most outdoor noise barrier, STC values of at least 25 or 30 are sufficient to ensure that no significant sound is transmitted through the barrier.

Specific Product Recommendations

Recent experience in other states highly recommends the Durisol product for new barrier construction, and the Industrial Acoustics Noishield panels or Pyrok spray for the retrofit application to existing walls.

The Durisol material has been in use along highways for over 30 years, and typically has shown virtually no wear or obvious degradation over that much time. It is very durable, efficient at absorbing sound (especially the thicker version with NRC of 0.8), is reasonably priced, and can be formed into a wide variety of shapes. For compatibility with the appearance of block barriers, Durisol can be formed and colored to look like block construction.

The Industrial Acoustics panels have also been in use for many years and have held up well outdoors. The attractiveness of this product is in its very high NRC (0.95, for practical purposes, means reflected-only sound is reduced by at least 13 dB) and its light weight. Also worthy of consideration for retrofit application is the spray-on Pyrok material. This is especially useful if quick and easy application is of particular value.

Devices Added to Barriers and Barrier Shapes

A number of devices are designed for placement on the top of noise barriers, to enhance their acoustical performance. Some of these devices have been shown to enhance noise barrier performance by small amounts, but the dramatic claims of improved acoustical performance are almost always for special conditions of geometry, or for frequencies that are not representative of typical highway situations.

In all cases, the practical improvements that these special devices produce are not justified by their cost. By simply increasing a barrier's height by a small percentage, the improvement that would be provided by such a device can be achieved at much lower cost and complexity. Only in the cases where barrier height is very strictly limited would it be practical to consider such a device.

One such device that has been shown to be effective is the "T" top barrier, where the width of a cap along the top of a barrier is several feet (5 to 8 ft). These barrier tops improve a barrier's acoustical performance somewhat, as shown by scale-model studies and full-scale studies conducted adjacent to highways.[6] That performance is enhanced further if absorptive material is applied to the cap's top.

One barrier shape that has been receiving some study recently is the random or jagged top barrier.[7] Instead of a smooth top edge, the barrier top has a random zig-zag pattern along its length. Some technical reports document improvement from this barrier top, while others document no improvement.

---

[6] May, D.N. and M.M. Osman, “The performance of sound absorptive, reflective and T-profile barriers in Toronto,” *Journal of Sound and Vibration,* Vol, 71, pp. 65-71, 1980.

[7] Menounou, P. and I. J. Busch-Vishniac, “Jagged Edge Noise Barriers,” *Journal of Building Acoustics,* Vol. 7, No. 3, 2000.

The Effect of Multiple Reflections Between Parallel Noise Barriers

Highways sometimes include cross sections where the roadway is depressed below grade and thereby flanked by vertical retaining walls. At other times, highways contain cross sections where the roadway is flanked by vertical noise barriers, one on each side. Other cross sections sometimes include a combination of vertical barriers and vertical retaining walls.

Two changes occur acoustically when a roadway is flanked in these ways by parallel barriers or retaining walls. First, direct lines-of-sight between receivers and traffic are interrupted by the intervening barrier or retaining wall. When this happens, some receivers no longer have direct view of some traffic-noise sources and the intervening barrier or retaining wall reduces noise levels at these receivers. And so noise is reduced for those receivers.

Second, the parallel barriers or retaining walls cause multiple reflections of the noise from side to side across the roadway. The resulting reverberation tends to increase noise levels at nearby receivers. This noise increase due to reverberation may partially offset the noise reduction due to interruption in the lines-of-sight. As a result, the intervening barrier or retaining wall does not provide as much noise reduction as it would without the reverberation—that is, without the presence of the barrier or retaining wall on the opposite side of the roadway.

The maximum increase in noise level due to a single reflection (for example, off of a single reflective noise barrier) is 3 decibels, which corresponds to a doubling in sound energy. In situations where parallel retaining walls or noise barriers permit multiple reflections to occur, noise levels may increase by more than 3 decibels. Measurements have verified this result and further indicate that the compromise in noise barrier performance (called “parallel-barrier degradation") increases as the ratio of the distance of separation of the walls to the height of the barriers or walls decreases.[8] As a very general rule, degradation of 3 decibels or greater may result when this ratio is less than about 10:1.

The use of noise-absorptive surfaces should always be considered if barriers are to be constructed on both sides of a highway. If absorptive surfaces are used, they would be necessary on the sides of all barriers facing the mainline. The best results would be obtained by applying a noise-absorptive surface (an NRC of 0.8 or greater is recommended) to the entire face of each barrier.

Application of absorptive treatment to just one of the two reflective surfaces will eliminate multiple reflections. However, noise barrier performance can still be degraded on the side of the road opposite the reflective surface.

1.2 General costs

Costs for newly built absorptive barriers appear in Table 1 (See page C-3). Facing material costs for retrofit applications appear in Table 2. The majority of installation costs appear as a range, which depends on the particular footing and structural conditions that exist at a given barrier location.

Costs for barriers with absorptive materials may be higher than costs for non-absorptive barriers. However, the added benefit from absorption might offset the added cost and actually result in a lower cost per benefited home.

---

[8] Fleming, Gregg G. and Edward J. Rickley, *Parallel-Barrier Effectiveness Under Free-Flowing Traffic Conditions.* Report No. FHWA-RD-92-068, Cambridge, MA: Transportation Systems Center, April 1992.

1.3 General location of benefited residences

The number of benefited residential properties might increase very slightly if noise barriers are given absorptive facings.

1.4 Benefit/cost ratios

Benefit/cost ratios would be extremely low for absorptive barrier facings, because the benefit is so very small.

1.5 Life cycles

Noise barriers and treatments listed in both Table 1 and Table 2, above, are designed to last 30 to 60 years, but could last longer.

1.6 Maintenance

Maintenance considerations for absorptive surfaces may include periodic cleaning or painting, depending on the product. Some absorptive walls are resistant to graffiti. Maintenance considerations for absorptive noise walls will vary by manufacturer.

1.7 General neighborhood acceptance

If absorptive facings are added to very attractive noise barriers, neighborhood acceptance might be very poor. This is especially true for barriers that artists have helped design—common around the Scottsdale area. Facings are surely not recommended for such noise barriers.

Where noise barriers are on both sides of a highway, noise levels at large distances might actually increase due to the barriers. In effect, they raise the acoustic center of the noise higher above the terrain, where it is more direct line-of-sight to distant receivers. In such situations, absorptive facings on the barriers would reduce distant noise levels.

By reducing degradation due to multiple reflections, absorptive materials may allow barriers to be shorter than otherwise (while providing similar benefit). Often, shorter barriers are more acceptable to residents because they are less intrusive visually, block less sunlight, and so forth.

By reducing degradation, absorptive materials increase the benefit of barriers. Often residents consider the noise reduction benefits vs. the visual intrusiveness of barriers. More noise reduction increases the benefit and should increase acceptance.

Sometimes a barrier is built on one side of a highway, only. The other side has no (or too few) close residences, perhaps. In this situation, use of absorptive materials should eliminate concern over noise reflections.

1.8 Detrimental environmental impacts

Environmental impacts of absorptive barriers are generally the same as reflective barriers. Some absorptive barriers are made using recycled materials, such as rubber from scrap tires.

1.9 Social considerations

The social impacts for absorptive barriers would be the same as for reflective barriers. Additional considerations are discussed in Section 1.7, above.

1.10 Aesthetics

Aesthetic treatments are available for some absorptive treatments, and colors and finish patterns can be similar to reflective barriers. A wide range of color choices, patterns, and styles are available for many barriers.

As discussed above, shorter barriers are often seen as better for aesthetics. Absorption may allow the barrier to be shorter.

1.11 Safety consideration

Typically, absorptive barriers would have to meet the same vehicle impact and fire resistance requirements as other barriers.

CHAPTER 2.0: HIGHWAY RE-SURFACING WITH ASPHALT RUBBER

Over the past years, several highway surface materials and treatments have been studied to determine whether significant noise reduction can be obtained with different highway surfacing. The Arizona Department of Transportation (ADOT) is now committed to using Asphalt Rubber Asphalt Concrete Friction Course (ARFC) for resurfacing projects on primary and secondary highways, once existing pavements reach the end of their design life. This commitment is primarily due to proven long-term performance of ARFC, as well as high public demand. Therefore, this discussion of highway re-surfacing will focus on ARFC surfaces.

Since the development of asphalt-rubber binders by Charles McDonald, using crumb rubber from recycled tires in the 1960s, ADOT has refined the specifications of asphalt-rubber surfacing mixes, and has been using them continuously for both surface replacement and new highway projects. Primary benefits of including rubber in the mix are improved durability and skid resistance of the surface. Other mechanical benefits include better-than-expected aging characteristics, plus resistance to rutting and fading. In more recent years, asphalt-rubber surfaces have gained popularity with the public and the press for their noise-reducing characteristics.

A one-mile test section on the Pima freeway was studied in the summer of 2002 to evaluate the noise reduction of ARFC relative to existing Portland Cement Concrete (PCC) pavements. Significant noise reductions of 4 decibels or more were recorded for all close-proximity and far-field tests. As a result, in April of 2003 ADOT proposed a pilot program to study highway traffic-noise reduction on twenty-seven highway segments in Arizona. The overlay of these segments is expected to be complete within three years. On the Pima Freeway, the Mountain View to Raintree Drive segment is scheduled to be overlaid in Fiscal Year (FY) 2004; the McKellips to McDonald Drive segment in FY 2005; and the McDonald Drive to 90th Street and Raintree Drive to Scottsdale Road segments in FY 2006.

Asphalt-rubber mixtures used in Arizona

Asphalt-rubber binders in current use by ADOT typically contain 80% paving-grade asphalt and 20% ground recycled tire rubber, also known as crumb rubber. For simple resurfacing of concrete pavements common on primary and secondary courses in Arizona, it is the preferred practice of ADOT to place ARFC in a ½- to 1-inch layer over the existing surface. To correspond to the test section in current use, this will be the resurfacing method that is now planned for the Pima Freeway.

On roadway segments where greater structural stability and impermeability of the surface is needed for longer design life, gap-graded mixtures are commonly used. Gap-graded mixtures tend to use lower percentage (by weight) of small-size aggregate, with a higher percentage of the larger aggregate. Open-graded mixtures exclude more of the smaller aggregate in favor of more uniform-sized larger aggregate. By contrast, it has been common practice in California to use mostly gap-graded mixtures for primary wearing surfaces.

Table 3 summarizes various pavement types. Within the table, PCC pavements (commonly called "concrete") and DGAC pavements (commonly called "asphalt") are the conventional surfaces most commonly used in the United States.

Table 3 An overview of pavement types

Surface Type	Abbreviation	Description
Portland Cement Concrete (commonly called "concrete")	PCC	The existing surface on the Pima Freeway. This surface is common for a high percentage of roadways in the southwest.
Asphalt Rubber Asphalt Concrete Friction Course	ARFC	The rubberized "quiet pavement" that is ADOT's current preferred asphalt mixture for resurfacing primary and secondary highways. This surface type contains a high percentage of coarse aggregate. Its composition is similar to OGAC in terms of inclusion of air voids, but also includes rubber in the mixture.
Asphalt Rubber Asphalt Concrete	ARAC	Another rubberized mixture, also known as "gap-graded" rubberized asphalt concrete. This surface type contains a lower percentage of air voids than ARFC and can be used as an absorptive middle layer with added structural properties for new highway projects, or for surface courses requiring more structural stability.
Open Graded Asphalt Concrete	OGAC	A concrete mixture containing only asphalt in the aggregate binder, with a high percentage of air voids—also considered a "quiet pavement." It contains a high percentage of coarse aggregate. It is used only for so-called surface courses.
Dense Graded Asphalt Concrete (commonly called "asphalt")	DGAC	A concrete mixture containing only asphalt in the aggregate binder. It is used for both structural and surface courses. It contains a higher percentage of finer aggregate and is the most commonly used mixture in the United States.
Stone Mastic Asphalt	SMA	An asphalt mixture that uses very coarse aggregate, in an all-asphalt binder mixture, to provide strength and resistance to rutting. It is similar to ARAC.

2.1 Achievable noise reduction

The following is a summary of the acoustical absorption properties of asphalt-rubber mixtures used as highway surface courses, as discussed in the technical literature. Highway surface treatments have the unique advantage of treating a primary cause of traffic noise at the source—contact of vehicle tires with the pavement.

As an introduction, study results contained in National Cooperative Highway Research Program (NCHRP) Synthesis 268 confirm that PCC pavements are generally noisier than asphalt pavements. From the summary section of that synthesis:[9]

> "Open-graded asphalt shows the greatest potential for noise reduction of side-line noise and reductions when compared to dense-graded asphalt. Reported reductions ranged from 1 to 9 dBA. However, the noise reductions seem to decline with surface age and in approximately 5 to 7 years much of the noise benefit has diminished, although the surface is still usually quieter than PCC [Portland Cement Concrete] pavements. Also, porous asphalt suffers from problems such as plugging and deterioration due to freeze/thaw cycles. Other asphaltic surfaces such as stone mastic and rubberized asphalt also hold promise, but do not appear to give the noise reductions of open-graded asphalt, although most are equal to or better than dense-graded asphalt."

---

[9] "Relationship between pavement surface texture and highway traffic noise," *NCHRP Synthesis 268*, Transportation Research Board, 1998.

Mechanisms of tire-pavement interface noise

Traffic noise is generated from multiple sources—including engine noise, exhaust noise, wind turbulence and the tire-pavement interface as individual vehicles travel over the surface.[10] Noise from engine and exhaust sources tend to be much more significant for medium and heavy trucks, compared to automobiles. At higher speeds (generally above 45 miles per hour), tire-pavement noise tends to dominate.[11]

Several mechanisms of tire-pavement interaction are described in the technical literature, as follows:[12]

- Slap-down effect. A slap-down effect occurs at the leading edge of the tire, as the treads meet the roadway. Air is forced out from between the tread elements and the roadway. This effect is generally called "air pumping."
- Tire vibrations. Tire vibrations, caused by irregularities in the pavement surface, occur in the tire-pavement contact patch. Some of the tire's kinetic energy is converted to acoustic energy.
- Trailing edge. Noise is generated at the trailing edge of the tire, as the tread is released from the road surface. Pressurized air trapped between the tread and the pavement is released (also part of "air pumping"). As the tread snaps back, a resonance effect is produced within the tire tread.
- Stick-and-slip. A stick-and-slip phenomenon produces high-frequency noise at the interface.

Another important factor to consider for pavements with air voids is that these air voids absorb sound energy as it propagates to nearby receivers. Figure 1, taken from the *Tire/Road Noise Reference Book* (p. 268),[13] illustrates the effect of multiple reflections under the carriage of the vehicle and subsequent propagation. For dense-graded surfaces, the pavement surface is highly reflective, resulting in minimal loss of sound energy. The open-graded absorptive surface absorbs some of this energy, lowering overall sound levels at the receiver.

Effects of air-void composition

Storeheier, as well as NCHRP Synthesis 268, found that increasing the percentage of voids in open-graded asphalt reduces noise levels. Synthesis 268 recommends porosity values greater than 20 percent. Storeheier's analysis, which was for low-speed vehicles (30 miles per hour), showed noise reductions increasing from 2.5 decibels at 15 percent porosity, to 3.4 decibels at 20 percent porosity, to 3.7 decibels at 25 percent porosity—all other factors being equal.

Additionally, Storeheier and others have shown that sound absorption in the porous pavement extends to lower frequencies as the thickness of the porous layer is increased. This is consistent with

---

[10] Henderson, M. JHK and Associates, "A comparison of Traffic Noise from Rubber Asphalt Concrete Friction Courses and Portland Cement Concrete Pavements" ADOT Report No. FHWA-AZ96-433, Feb. 1996.

[11] Ibid.

[12] Ibid.

[13] Sandberg U., J.A. Ejsmont. "Road surface influence on noise emission", *Tyre/Road Noise Reference Book*, INFORMEX, Sweden, 2002.

the acoustical behavior of any sound-absorbing material placed against an impervious surface. Storeheier's data show that overall (A-weighted) sound-level reduction is improved about 1 decibel by increasing the thickness of a porous pavement layer (porosity 24% to 27%) from 25mm to 100mm.

A report published in September 2001, summarizes three years of study on the performance of OGAC along a section of I-80 in Davis, California.[14] The OGAC overlay is 25mm (1 inch) thick. The baseline pavement on I-80 was old DGAC, not the louder PCC. The new open-graded overlay did not lose any of its noise-reducing capacity in the three years it was studied.

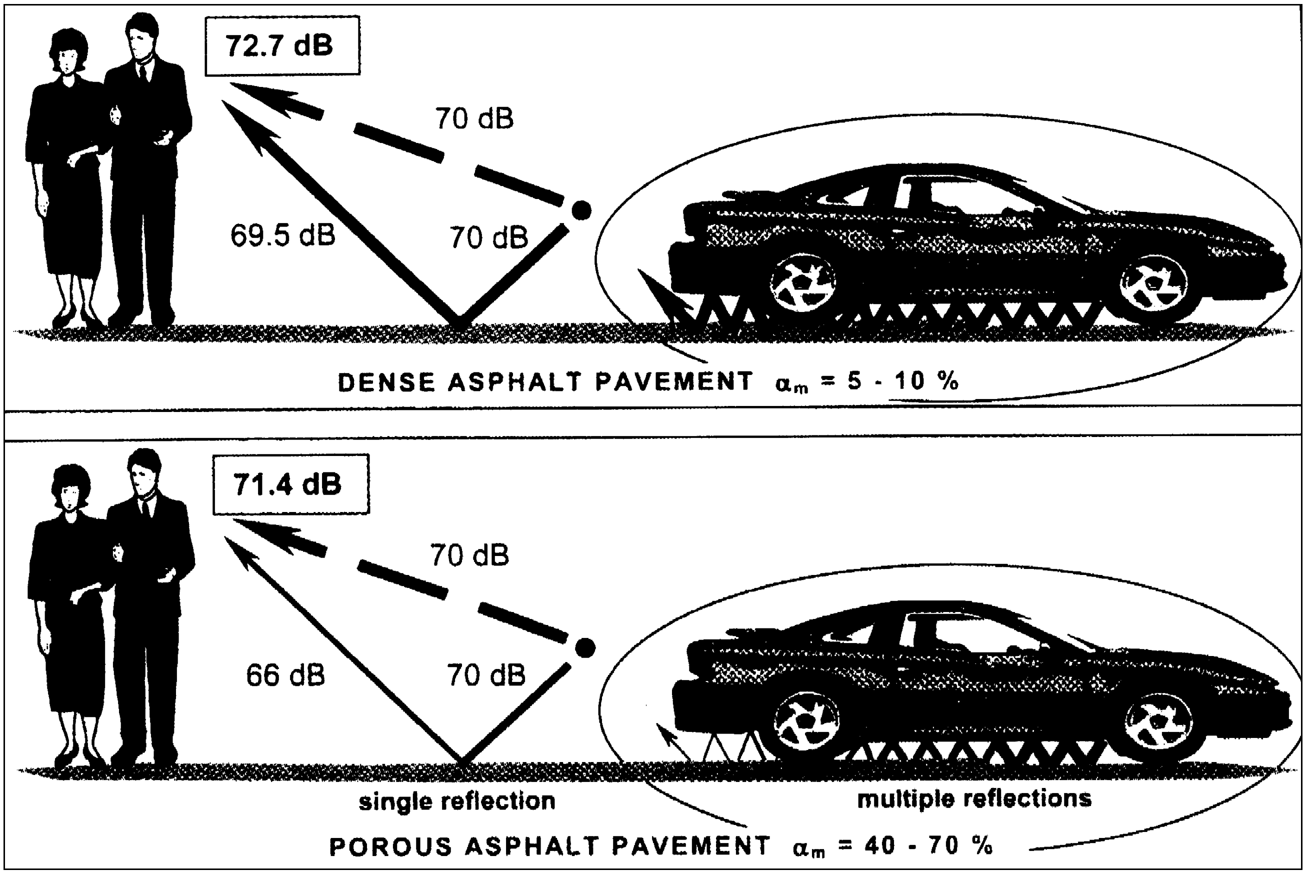

Figure 1 Acoustical effect of porous asphalt pavement versus dense asphalt pavement

All of the benefit (relative to DGAC) was in the 1/3-octave bands at 1000 Hz (pronounced Hertz, meaning cycles per second) and above, where the OGAC acts as an absorptive, pressure-release surface, and where the DGAC pavement is at its noisiest. The improvement in the upper frequency bands is between 5 and 10 decibels, where the human ear is most sensitive. Vehicle noise levels continue to be 4 to 6 decibels (overall, A-weighted) lower after three years.

---

[14] "I-80 Davis OGAC Pavement Noise Study, 3-Year Summary Report" prepared by Illingworth & Rodkin, Inc. for the California Department of Transportation, Sacramento, CA, September 17, 2001.

Clearly, air-void composition is a significant factor in reducing noise. Studies are currently inconclusive about whether a significant acoustical benefit accrues due to the rubber content of the surface, laid according to current hot-mix specifications.

It is the current practice of ADOT to design ARFC surfaces with a minimum air-void composition of 15 percent. Generally the mixes contain at least 18 percent air voids. This composition allows for good structural stability and durability of the surface, along with good drainage and noise reduction characteristics. ADOT places surfaces at different thicknesses, depending on the requirements of the application. For resurfacing of PCC, the ARFC is placed as a ½- to 1-inch layer.

Effects of aggregate size

NCHRP Synthesis 268 states: "the surface aggregate size is important and should be kept below 10 mm if possible. Larger chippings … the increased megatexture generates more low frequency noise from rolling vehicles due to increased tire vibration." Small chipping sizes, however, have slower, less efficient drainage.

It is the current practice of ADOT to use aggregate sizes no larger than 9.5mm (3/8-inch) for ARFC surfaces.

Traffic-noise studies of asphalt-rubber surfaces

Past noise studies generally lack sufficient documentation to understand (and fully quantify) the acoustical benefit of asphalt-rubber surfaces. Missing from these studies is important information about some (or all) of the following important control variables:

- "Before" and "after" pavement types and compositions
- Traffic volumes and vehicle classifications
- Vehicle traveling speeds
- Atmospheric conditions
- Distance from roadway centerline for wayside measurements
- Age of surfaces.

Lacking sufficient documentation, the precise acoustical benefits of asphalt-rubber surfaces are currently unclear. The *Quiet Pavement Pilot Program* in Arizona, as well as current controlled studies in the Los Angeles area, is expected to clarify the acoustical benefits of ARFC, as an alternative to other surfaces.

Past noise studies in Arizona and California include the following:

- <u>Route 101 Scottsdale, Arizona</u>. ADOT performed far-field and close-proximity sound intensity measurements on a section of Route 101, the Pima Freeway:[15]

  > "Based on citizen input in the Scottsdale area regarding a section of SR 101, a one-mile long section of PCCP was overlaid with ARFC to demonstrate the effectiveness of the quiet pavement strategy. Before and after close proximity testing indicated that there was approximately an 11-dBA difference in noise levels."

---

[15] Attachment 5, *Arizona Department of Transportation Quiet Pavement Pilot Program*, April 16, 2003.

Far-field measurements taken at adjacent residences were found to be 4 to 7 decibels quieter after ARFC was overlaid on PCC pavement.

- Phoenix and Tucson, Arizona. A report published in February 1996 by JHK and Associates[16] summarizes a survey of traffic-noise levels from PCC and ARFC pavements. The study concluded that ARFC surfaces were 1-to-5 decibels quieter than PCC pavement during roadside measurements. For close-proximity measurements, ARFC was approximately 2 to 3 decibels quieter than PCC. The difference was most noticeable in the 800 to 3150 Hz 1/3-octave bands, the frequencies at which the human ear is most sensitive. The report further observed, "…differences in pavement surface texture are likely to be a critical factor in the relative noise levels produced by the PCCP and [ARFC] segments evaluated in this study."
- Thousand Oaks, California. A report published in December 2002 by Acoustical Analysis Associates, Inc.[17] summarizes a measurement program in the city of Thousand Oaks, California. Wayside measurements were taken at several arterial highways with ARAC surfaces, and two streets with DGAC surfaces were used as control samples. Noise reductions of 2 to 5 decibels were measured after normalizing traffic volumes. The study additionally concluded that the measured noise reductions were highly dependent on vehicle travel speeds. This finding is consistent with the relative tire-noise contributions from automobiles—at high speeds, tire-pavement interface noise is the dominant highway noise source; at lower speeds, engine and exhaust noise are more significant contributors to overall vehicle source noise levels.
- Sacramento, California. Several noise studies published in Sacramento County[18] by Brown-Buntin Associates and Bollard & Brennan, Inc. in the mid-1990's evaluated the noise levels of ARAC surfaces, relative to the overlaid DGAC surfaces. Noise reductions of 5 to 7 decibels were measured for new ARAC, relative to old DGAC, on a section of Alta Arden Expressway during a wayside measurement program in Sacramento. After 16 months of service, noise reductions from the same measurement locations were measured to be 1 to 5 decibels. This study concludes that noise reduction benefits of asphalt-rubber surfaces are evident, but may decline with age. Another similar study performed on Antelope Road in Sacramento reported noise reductions of 4 decibels.

Effects of pavement surface aging

The effect of age on reduced noise from asphalt-rubber surfaces is also unclear. Due to the recycled tires that are added to the mixture, the surface inherently possesses good aging characteristics, provided specifications are met at the hot-mix plant and construction occurs under acceptable climate conditions. Several studies have indicated that reduced noise from these surfaces may decline with age, perhaps by one decibel every 2 to 4 years.

---

[16] Henderson, M. JHK and Associates, "A comparison of Traffic Noise from Rubber Asphalt Concrete Friction Courses and Portland Cement Concrete Pavements" ADOT Report No. FHWA-AZ96-433, Feb. 1996.

[17] "Asphalt Rubber Overlay Noise Study Update" (for the city of Thousand Oaks, CA) prepared by Acoustical Analysis Associates, Inc. for the County of Sacramento, Sacramento, CA, December 2002.

[18] "Report on the Status of Rubberized Asphalt Traffic Noise Reduction in Sacramento County," prepared by Bollard & Brennan, Inc. for the County of Sacramento, Sacramento, CA, November 1999.

Current acoustical specifications of asphalt-rubber as used in Arizona

While past studies lack sufficient documentation to precisely determine benefit, they provide enough evidence to support the claim that asphalt-rubber surface courses provide real acoustical benefits—even though these benefits are not fully quantified.

As a result of the noise-level studies performed recently on Route 101 (the Pima Freeway), ADOT currently ascribes a 4-decibel noise reduction to ARFC pavements. This 4-decibel reduction is not relative to noise levels from existing PCC pavements in Arizona. Instead, it is relative to the “average” pavements built into both FHWA computer programs: STAMINA and TNM.[19] As a result, this 4-decibel noise reduction for AFRC pavements is most likely an underestimate of benefit from re-surfacing the Pima Freeway, because the freeway starts out with relatively loud PCC pavement—most likely louder than “average” pavement.[20]

To predict future noise levels along ARFC pavements, a minus 4-decibel “adjustment factor” would be applied to TNM’s computed average-pavement results. Alternatively, this adjustment can be applied with the older model, STAMINA, using a 4-decibel “shielding factor.”

ADOT is committed to provide alternative abatement if ARFC does not provide 4 decibels of noise reduction. This quote from the text of the *Quiet Pavement Program* summarizes that ADOT commitment:[21]

> “If measurements after ARFC construction determine that a reduction of at least 4 dBA is not being achieved, ADOT agrees to the following to provide necessary measures to abate highway traffic noise levels in perpetuity.
>
> If quiet pavements are used as a noise mitigation strategy in the noise modeling, and it is determined the pavement has not achieved the assumed level of mitigation, ADOT will resurface the roadway to achieve the assumed level of noise reduction or provide a similar level of noise mitigation through more conventional techniques, like barrier walls or berms.”

Resurfacing of Residential Roads

It has been suggested that adding Asphalt-Rubber surfacing to side streets may enhance the overall noise benefit of quiet pavements on the freeway. While overall sound levels would decrease as a result, the actual amount of the decrease would be far too small to be perceptible (noise differences of less than 3 decibels are not perceptible to the human ear). One reason for this is that the relative volumes on side streets are much fewer than the traffic volumes on the mainline. In addition, engine and exhaust sources tend to contribute more to the overall vehicle sound levels at slower speeds (less than 45 mph), because tire-pavement interface noise would be quieter. Due the combination of these factors, the maximum additional cumulative benefit that could be achieved by resurfacing residential roads in addition to the mainline would be less than one decibel.

---

[19] Attachment 5, *Arizona Department of Transportation Quiet Pavement Pilot Program*, April 16, 2003.

[20] Personal observation.

[21] Attachment 5, *Arizona Department of Transportation Quiet Pavement Pilot Program*, April 16, 2003.

2.2 General costs

The initial cost of rubber-asphalt surface can be higher than conventional surfacing, but the life cycle costs tend to be lower due to lower maintenance costs and demonstrated, long life cycles.

According to the Rubber Pavements Association (www.rubberpavements.org in Tempe, AZ), the cost of asphalt-rubber surfacing is nearly half of what it was in 1985. In particular, Asphalt-Rubber Hot Mix now costs approximately \$2.50 per square yard (for one inch thickness), compared to \$1.35 per square yard for conventional asphalt concrete. Used in a friction course, Asphalt Rubber costs about \$2.15 per square yard, compared to \$1.55 per square yard for conventional mixes.

In aggregate, these unit costs total to approximately \$350,000 per mile to resurface the Pima Freeway, including shoulders and ramps.

2.3 General location of benefited residences

Residences are “benefited” if they receive a “significant noise reduction.” Current ADOT policy considers a “significant noise reduction” to equal 5 decibels or more at residences predicted greater than 64 dBA (without mitigation). In consideration of alternative noise abatement measures, ADOT has recently decided to modify their policy so that residences that receive 3-decibels of noise reduction are counted as “benefited.”

With this modification, a 4-decibel reduction due to ARFC re-surfacing is a “benefit.” Because acoustical benefits decrease with distance, realistically this benefit only accrues at the closest two rows of residences along the freeway.

2.4 Benefit/cost ratios

Benefit/cost ratios differ for each neighborhood along the Pima Freeway. Specific neighborhood values depend upon the length of freeway near that neighborhood and the number of benefited residences in the first two rows of homes.

These values derive from the following equation:

$$\begin{pmatrix}\text{approximate}\\ \text{benefit/cost}\\ \text{ratio}\end{pmatrix}=\frac{\text{number of residences receiving 4dB benefit in first two rows}}{(\$350,000)(\text{length of adjacent Pima Freeway in miles})}.$$

However, because the entire length of the Pima Freeway will be repaved as part of the ADOT pilot program discussed in the beginning of this section, a comparison by neighborhood of benefit/cost ratios for the freeway is not necessary. A comparison of benefit/cost ratios based on the above formula might prove more useful except that the analysis shows that rubberization of the cross-streets is not an effective mitigation strategy (see Section E.2.1)

2.5 Life cycles

The actual design life of ARFC has not yet been established. For resurfacing of PCC, as on the Pima Freeway, 1-inch overlays of ARFC are designed to last 7-to-10 years.[22] Several instances of ARFC re-surfacing (on top of PCC and DGAC) in Arizona have maintained good performance after 13 years of service.

2.6 Maintenance

Asphalt-rubber surfaces have required significantly less maintenance and rehabilitation than conventional pavements, resulting in lower annual maintenance costs per lane-mile.

2.7 General neighborhood acceptance

Asphalt-rubber surfaces are highly desirable to the public. There is a high public demand for these surfaces. Both motorists and residents living adjacent to highways observe their noise reduction relative to conventional surfaces. Therefore, positive neighborhood acceptance for ARFC re-surfacing is expected.

2.8 Detrimental environmental impacts

The public has expressed some concern about air quality and the production of asphalt-rubber binders in hot-mix plants. Three studies performed in Texas, Michigan and California have concluded that “rubber does not contribute significantly to any increase in undesirable compounds.”[23] In addition, “the effect of [crumb rubber] on emissions may be relatively small in comparison to the effects of other variables.”[24]

Fumes from asphalt-rubber mixes can be objectionable, particularly during surface application.[25] Asphalt additives are available to help moderate this problem.

2.9 Social considerations

There are many social benefits of using recycled tires for ARFC re-surfacing of the Pima Freeway. These include:

- Reduced traffic noise levels. As discussed above, several studies have shown that ARFC surfaces are quieter than the existing PCC pavement common on Arizona highways—including on the Pima Freeway.
- Less frequent traffic restrictions. ARFC is commonly applied as a thin surface, therefore requiring less construction time.

---

[22] Carlson, D. “Rehabilitation of Portland Cement Concrete Pavements With Thin Asphalt-Rubber Open Graded Friction Course Overlays in Arizona”, A publication of the Rubber Pavements Association, Tempe, Arizona, 2002.

[23] “Air Quality Issues and Best Management Practices with the Production of Asphalt-Rubber Asphaltic Concrete,” A publication of the Rubber Pavements Association, Tempe, Arizona, 2002.

[24] Ibid.

[25] Ibid.

- Fewer traffic delays. ARFC surfaces that are constructed under the correct design conditions tend to have longer design lives than conventional pavements. This results in lower maintenance and fewer rehabilitation requirements that interrupt/constrict traffic.
- Reduced splash and spray. ARFC surfaces (particularly open-graded mixes) have more efficient drainage than conventional surfaces. This property helps to reduce the splash and spray of rainwater from vehicles, improving visibility.
- Reducing tire stockpiles in landfills. ARFC re-surfacing improves overall public health and safety. One thousand tires are recycled per lane-mile of ARFC.[26]
- Good pavement marking visibility. ARFC tends to retain its dark color as it ages, thus providing long-lasting high contrast to pavement markings—and also improving safety and reducing the need for routine maintenance.
- Improved traffic safety. ARFC has better skid resistance and resistance to rutting than conventional surfaces.
- Reduced energy requirements. Because ARFC mixes are applied as thin layers for resurfacing, less energy and natural resources are required.[27]

2.10 Aesthetics

When ARFC surfaces are constructed according to the correct conditions and mixtures, they have longer life cycles and better resistance to rutting and cracking. This reduces the need for patching and other repairs that are usually necessary as pavements age. Therefore, the quality and appearance of the roadway surface does not degrade as much over time, compared to conventional surfaces. Less maintenance and rehabilitation is required, reducing the need for construction vehicles. In addition, when roadways maintain their initial good quality over their full design life, the overall attractiveness of the neighborhood is improved.

Additionally, the surface maintains its dark color for longer periods of time, due to the excellent aging properties of the asphalt-rubber mixture. This allows for a high level of contrast between pavement markings and the roadway surface.

Another aesthetic consideration involves ARFC substitution for noise walls. ARFC does not significantly alter the surrounding landscape, as do noise walls. Where both are required to meet design goals, ARFC meets part of the goal and so noise-wall height can be significantly reduced.

2.11 Safety considerations

ARFC surfaces have better resistance to rutting and cracking than conventional pavement surfaces.[28] They also have good skid resistance throughout their design life. This is due to the combination of

---

[26] Carlson, D. “Rehabilitation of Portland Cement Concrete Pavements With Thin Asphalt-Rubber Open Graded Friction Course Overlays in Arizona”, A publication of the Rubber Pavements Association, Tempe, Arizona, 2002.

[27] Hicks, R.G. “Asphalt Rubber Design and Construction Guidelines, Volume I – Design Guidelines,” prepared for Northern California Rubberized Asphalt Concrete Technology Center, January 2002.

[28] Carlson, D. “Rehabilitation of Portland Cement Concrete Pavements With Thin Asphalt-Rubber Open Graded Friction Course Overlays in Arizona”, A publication of the Rubber Pavements Association, Tempe, Arizona, 2002.

the rough surface texture of the aggregate and the high percentage of air voids in the surface layer, which allows for drainage of standing water from the pavement surface.

CHAPTER 3.0: TRAFFIC MANAGEMENT

On local and arterial streets, traffic management can sometimes produce modest noise mitigation. Such traffic-management measures include:

- Reduced speed limits, which slow vehicles down and reduce their noise emissions modestly,
- Traffic signals and stop signs, which also slow vehicles down and thereby reduce their average noise emissions,
- Truck prohibitions, which eliminate the loudest vehicles on the roadway, and
- Time-use restrictions for trucks, which eliminate the loudest vehicles during the most noise-sensitive times of day.

Such measures, however, are hardly ever acceptable on limited-access highways such as the Pima Freeway. They strongly conflict with the primary purpose of freeways—to deliver goods and services over long distances, with speed, and to bypass traffic (especially truck traffic) around more congested areas. Traffic-management restrictions on the Pima Freeway would divert traffic onto local streets, closer to its nearest neighbors, where it would produce even greater noise impact.

None of these measures is reasonable from a service point of view for the Pima Freeway project.

3.1 Achievable noise reduction

Minimal noise reduction is possible with speed constraints and truck prohibitions. These are not sufficient however to consider for the Pima Freeway.

Speed constraints

Even if thought reasonable from a service point of view, reduction of posted speed limits is not an effective noise-mitigation measure on freeways.

First, such reductions often do not succeed in significantly reducing actual vehicle speeds on the freeway, unless they are very vigorously enforced.

Second, even if such postings did succeed in reducing average Pima Freeway speeds from 65 to 55 miles per hour, for example, that speed reduction would yield a noise reduction less than 3 decibels. Such a small reduction is not acoustically significant, because it is too small to be perceived as a benefit by neighbors to the freeway.

Truck restrictions

Even if though reasonable from a service point of view, truck restrictions are generally not capable of significantly reducing Pima Freeway noise levels—because automobiles are a major contributor to the overall sound level. Because automobiles comprise over 90 percent of vehicle volumes during the loudest hours of the day, only modest reductions in noise levels could be achieved by totally eliminating truck traffic from the freeway.

3.2 General costs

There are no costs associated with the implementation of traffic restrictions, other than the cost of installing traffic signs or signals. The freeway user could incur costs due to lost time detouring around the road, or traveling at slower speeds on the road.

3.3 General location of benefited residences

Truck or speed (reducing the speed limit by 10 miles per hour) restrictions would result in lower noise levels (about 2-decibels of noise reduction), but would not provide any required substantial noise benefit to residential properties.

3.4 Benefit/cost ratios

This is not applicable since there are no residences that would receive substantial benefit.

3.5 Life cycles

Life cycle considerations are not applicable to traffic management.

3.6 Maintenance

There are no maintenance considerations associated with traffic management.

3.7 General neighborhood acceptance

Overall neighborhood acceptance issues are unclear for this measure. Some residents may favor the convenience of living adjacent to a high-speed arterial, while others may favor the improved safety that could result from reducing the speed limit of the road.

3.8 Detrimental environmental impacts

Traffic management has no detrimental environmental impacts.

3.9 Social considerations

Traffic management has no social consequences for residents, but could be irritating to the user of the roadway facility.

3.10 Aesthetics

No aesthetic issues need to be considered for traffic management.

3.11 Safety considerations

Lower vehicle traveling speeds generally translates to mean safer roads. Safety considerations would be the only real benefit to traffic management. Safety considerations would have to be weighed against the neighborhood and user disruptions that would result from the implementation of truck restrictions and lower traveling speeds.

CHAPTER 4.0: LAND USE CONTROLS

Land use controls can reduce residential noise impact—especially for lands not yet developed. Land use controls can be of three types:

- Buffer zones. Zoning designation that prevents all construction close to a freeway. The resulting open space (buffer zone) increases distances between the freeway and nearest residences, thereby reducing their noise impact. In general, commercially zoned buffers are preferable to “empty-space buffers, because intervening commercial buildings further reduce noise levels.
- Appropriate development. Zoning designation that prevents new residential construction close to a freeway—perhaps based upon distance, or perhaps based upon measured noise levels, instead.
- Building-construction requirements. Construction requirements for new residences built within particular land-use zones.

Such land-use controls are primarily useful to reduce aircraft noise impact. In contrast, such land-use controls are not needed for Scottsdale along the Pima Freeway, because all undeveloped Scottsdale lands abutting the freeway are zoned commercial or industrial. This includes future development north of Raintree Drive.

CHAPTER 5.0: VEGETATION

The use of vegetation for noise mitigation is not feasible for the Pima Freeway. Vegetation zones of any reasonable size along the freeway would not provide significant noise reduction. Even if vegetation were feasible for noise mitigation, high levels of maintenance would be required to establish initial growth and for general care throughout vegetation lifetimes.

5.1 Achievable noise reduction

The FHWA Traffic Noise Model (TNM) contains within it the latest professional consensus on noise reduction produced by vegetation. The equations within TNM conform to accepted standards of the International Standards Organization.

According to the equations within TNM, a band of vegetation parallel to the Pima Freeway would have to be approximately 150 feet wide to provide 4 decibels of A-weighted broadband attenuation to freeway neighbors. Moreover, that vegetation would have to be sufficiently dense to completely block line-of-sight to the vehicles traveling on the roadway from neighbor homes. This blockage would have to extend to the ground, as well, requiring dense undergrowth as well as dense tree foliage.

In most places along the Pima Freeway, insufficient right-of-way exists for this 150-foot wide vegetative zone. There are large tracts of undeveloped open space (as much as 3,500 feet exists between the freeway and residences) between McKellips Road and 90th Street; however, these areas lie on the Salt River Pima Indian Reservation and outside the City limits. Even if right-of-way within the City limits were available, vegetation of this density needs decades to grow. It cannot be initially planted dense enough.

5.2 General costs

Initial and regular maintenance costs would need to be considered for vegetative noise mitigation. Maintenance costs would vary depending on the type of vegetation chosen, and whether vegetative sculpting is considered important.

5.3 General location of benefited residences

Vegetation could provide a small degree of noise reduction, but not enough to provide substantial noise benefit to residential neighborhoods. No residences would be officially “benefited.”

5.4 Benefit/cost ratios

This is not applicable since there are no residences that would receive substantial noise benefit.

5.5 Life cycles

Plant life cycles vary, and would need to be considered in vegetation maintenance.

5.6 Maintenance

Highway landscaping would need to be a regular component of highway maintenance for noise-mitigation vegetation. The arid climate in Scottsdale would inhibit the initial growth of the vegetation, and much maintenance would be required initially to establish even moderate growth. Additionally, a significant amount of highway right-of-way would be required for vegetation to be of sufficient thickness out from the freeway.

Even if vegetation could provide significant benefit (which it cannot), maintenance issues due to Scottsdale climate would likely prohibit the serious consideration of vegetation as an option for noise mitigation.

5.7 General neighborhood acceptance

Vegetation is likely to be accepted by neighbors to the Pima Freeway. Vegetation is aesthetically pleasing and it blocks the view of the freeway, in addition.

Vegetation thereby provides psychological benefit, which is useful for very moderate amounts of highway noise. Against more substantial highway noise, however, vegetation is powerless.

5.8 Detrimental environmental impacts

If properly maintained, vegetation would not detrimentally impact the environment, but instead it would enhance it.

5.9 Social considerations

Vegetation is a pleasing addition to neighborhoods and roadways.

5.10 Aesthetics

The aesthetic benefits of using vegetative barriers along roadways are obvious, even though acoustically they are ineffective.

5.11 Safety considerations

Vegetation does not have any safety issues, provided the vegetation types are compatible with the surrounding land use.

CHAPTER 6.0: PROPERTY ENHANCEMENTS: RESIDENTIAL SOUND INSULATION

Highway noise penetrates into residences through walls, windows and doors—where it can interfere with TV, music, conversation and sleep. Sound insulation of residences near the Pima Freeway could reduce interior sound levels and provide significant improvement.

Residential sound insulation is far more common around airports than near major highways. In general, this is true because federal funds and airport-user fees are sometimes available for that purpose.

In contrast, federal funds are not available to insulate residences against highway noise—except under the most extraordinary circumstances. For that reason, less is known about insulation costs and methods to reduce highway noise. The information in this section has been estimated from experience near airports. Aircraft noise is lower in “pitch” than is highway noise. For this reason, it is fundamentally easier to insulate against highway noise than against aircraft noise. And in turn, costs are most likely less, as well.

Two informational booklets accompany this report section:

- Sound Insulation of Homes (Appendix D)
- Sound Insulation of Homes: A very Approximate Self-Diagnosis (Appendix E)

These booklets can guide individual homeowners towards improving the insulation of their homes against Pima Freeway noise. They contain much information beyond that in this current appendix. In addition, they contain references to web sites for additional technical discussion, as well as for specific sound-insulation products.

6.1 Achievable noise reduction

Residential sound insulation can reduce indoor noise levels between 5 and 10 decibels, but only within rooms that are insulated.

6.2 General costs

Table 4 lists approximate average costs for components of residential sound insulation.

Table 4 Sound insulation components and their approximate costs

Sound-insulation component	Approximate average unit cost
Glass fireplace screen	$ 300 each fireplace
Acoustical door gasketing	$ 50 each door
Acoustical window gasketing	$ 100 each window
Solid-core exterior door	$ 250 each door
Acoustical storm window	$ 400 each window
Acoustical storm door	$ 400 each door
Acoustically rated primary/storm window assembly	$ 1000 each window
Acoustically rated primary/storm door assembly	$ 2000 each door

Note: All costs are highly approximate.

Total costs are more difficult to determine than unit costs. Total costs depend upon what is acoustical needed for satisfactory improvement, how much the homeowner values a quieter home, the house size and number of stories, and whether or not windows and doors are standard size.

In general, only three sides of a house will need improvement. The side facing directly away from the highway will not. A lower cost range might be \$3,000 to \$6,000 to achieve 5 decibels of noise reduction—for a single-story house with new window/door gasketing, a new solid-core exterior door, and storm windows and storm doors. The range depends mostly upon the number of windows. In contrast, an upper cost range might be \$8,000 to \$15,000 to achieve 10 decibels of noise reduction—for full replacement of windows and doors with acoustically rated ones in a two-story house.

A rough average value is approximately \$6,000 per house; this is weighted more towards single-story homes not needing acoustically rated windows or doors.

6.3 General location of benefited residences

Benefited residences can be at any distance from the highway. It is not too likely, however, that owners of very remote homes would spend much money for sound insulation against the freeway.

6.4 Benefit/cost ratios

Benefit cost ratios might range from a low of 5dB/\$6,000 to a high of 10dB/\$8,000.

6.5 Life cycles

Most sound-insulation components have lifetimes equal to those of a normal house—perhaps 40 to 50 years. Exceptions are door and window gasketing, which needs replacement every decade or so.

6.6 Maintenance

Maintenance of most sound-insulation components parallels that for normal, non-acoustical building components. Gasketing requires no maintenance, but must be replaced periodically. Storm window and doors require routine homeowner maintenance. Wooden versions obviously require periodic painting, as do wooden versions of acoustically rated windows and doors. Other than painting, acoustically rated products require essentially no maintenance.

6.7 General neighborhood acceptance

Storm windows and doors can be seen by neighbors. Many of them look very similar to non-acoustical varieties—which are rare, however, in Scottsdale. For this reason, neighbors will notice some difference. Many acoustically rated windows and doors have a distinctive look, which may cause the house to stand out from its neighbors.

6.8 Detrimental environmental impacts

Residential sound insulation has no detrimental environmental impacts.

6.9 Social considerations

Residential sound insulation has no social consequences.

6.10 Aesthetics

If chosen well, sound-insulation components look very similar to normal building components. Their aesthetics will depend upon the homeowner’s concern for aesthetics in choosing manufacturers and models. Some acoustically rated doors are made of metal, which can look industrial.

6.11 Safety considerations

Improved sound insulation means less air leakage from outdoors to indoors. Some people have reported increased indoor pollution when homes are made more airtight—either for acoustical reasons or for energy efficiency. Other than this possibility, sound insulation has no safety considerations.

CHAPTER 7.0: PROPERTY ENHANCEMENTS: SOUND MASKING

Where highway noise is not severe, more pleasant sounds can sometimes be used to partially “cover up” the highway noise and thereby reduce its annoyance. The technical term is “sound masking.”

Outside the home, small fountains or water cascades produce a far more pleasant sound than do highways. Falling water is an excellent sound masker, outdoors. Outdoor background music could also be used, but may cause neighbor complaints.

Similar water sounds are possible within homes, as well, from small self-contained fountains. Background music is also often used to improve the acoustic climate indoors. In addition, sound from high-speed fans can mask highway noise from outside. Further, small electronic devices now are sold just to mask unpleasant noise. These devices sometimes produce so-called “white noise” and sometimes produce other pleasant, continuous sounds like ocean surf.

Masking noise has its limits, however. Sound masking works much like perfume. It can cover up moderate amounts of less pleasant noise, but it is repugnant itself, at large doses. Very loud masking noise is needed to cover up very loud highway noise. While the sound level of masking devices is really at the discretion of the user (taking into account potential annoyance to neighbors), sound masking generally should not be considered a feasible alternative for mitigating traffic noise impacts.

Sound levels above 60 dBA begin to cause activity interference, such as normal conversation outdoors. With normal voice effort and satisfactory sentence intelligibility, face-to-face communication at a distance of 6 feet can occur in a steady background of 60 dBA.[29] This could be considered typical for normal conversation around a patio table. At louder background noise levels, a raised voice would be required to communicate with the same degree of intelligibility. At the ADOT traffic noise impact criterion of 64 dBA, the distance for normal speech intelligibility decreases to about 4 feet.

These considerations can be used as a guideline for designing a practical upper limit requirement of generated sound levels that could be specified for outdoor sound masking devices. Refer to Appendix D for further information.

7.1 Achievable noise reduction

Masking noise does not actually reduce sound levels. In fact, it combines with the highway noise to increase the total somewhat. In other words, the composite noise—highway plus masking—is louder than highway noise, alone. In spite of this, masking noise is effective because it makes the composite noise more pleasant. In effect, it “covers up” the annoying quality of the highway noise.

7.2 General costs

Fountains and water cascades have a huge price range—perhaps $100 for a small indoor fountain, to several thousand dollars for a large outdoor fountain or waterfall. In contrast, background music and

---

[29] “Information on levels of environmental noise requisite to protect public health and welfare with an adequate margin of safety” prepared by the U.S. Environmental Protection Agency Office of Noise Abatement and Control, March 1974.

high-speed fans are essentially free, because they generally already exist around the house. Electronic sound-masking devices generally cost $100 or so.

7.3 General location of benefited residences

Benefited residences are those whose owners install sound masking. Indoor masking generally works throughout a single room. Outdoor masking decreases with distance from the sound-producing device. It would be uncommon for it to benefit an entire back yard, however.

7.4 Benefit/cost ratios

For lack of any actual noise-reduction benefit, benefit/cost ratio for this mitigation alternative cannot be computed. Nevertheless, this alternative is beneficial.

7.5 Life cycles

Life cycles range from several years (for electronic masking devices) to several decades for falling-water sound sources.

7.6 Maintenance

Most sound-masking sources are free of maintenance. When they wear out (high-speed fans, for example), they need replacement. On the other hand, large falling-water sound sources need the obvious routine homeowner maintenance.

7.7 General neighborhood acceptance

Outdoors, sound masking from water flow is generally accepted, and sometimes appreciated, by neighbors. On the other hand, outdoor music can cause neighbor complaints, especially when neighbors enjoy different types of music.

Neighbors will never hear indoor sound masking.

7.8 Detrimental environmental impacts

Sound masking has no detrimental environmental impacts.

7.9 Social considerations

Sound masking has no social consequences.

7.10 Aesthetics

Outdoor fountains and waterfalls can look great or not, depending upon taste. Other sound maskers have no aesthetic consequences.

7.12 Safety considerations

Most sound maskers have no safety consequences. Possible exceptions include high-speed fans, which can cut, and pools of water large enough to entice swimmers.