

Quieter Pavements: Options and Challenges for Washington State

May 2005



**Washington State
Department of Transportation**

Quieter Pavements: Options and Challenges for Washington State

May 2005

Prepared by:

State Materials Laboratory
Washington State Department of Transportation

and

Acoustics Section
Washington State Department of Transportation

Americans with Disabilities Act (ADA) Information

Persons with disabilities may request this information be prepared and supplied in alternate formats by calling the WSDOT ADA Accommodation Hotline at 360-705-7097. Persons who are deaf or hard of hearing may access Washington State Telecommunications Relay Service or Tele-Braille by calling 7-1-1.



**Washington State
Department of Transportation**

Contacts

Tom Baker, PE
State Materials Engineer
PO Box 47365
Olympia, WA 98504-7365
Phone: (360) 709-5401
E-mail: bakert@wsdot.wa.gov

Linda Pierce, PE
State Pavement Engineer
PO Box 47365
Olympia, WA 98504-7365
Phone: (360) 709-5470
E-mail: piercel@wsdot.wa.gov

Kim Willoughby, PE
Pavement Structures Engineer
PO Box 47365
Olympia, WA 98504-7365
Phone: (360) 709-5474
E-mail: willouk@wsdot.wa.gov

Mia Waters
Acoustics Program
Phone: (206) 440-4541
E-mail: watersy@wsdot.wa.gov

John Maas
Acoustics Program
Phone: (206) 440-4545
E-mail: maasja@wsdot.wa.gov

Contents

	Page
Executive Summary	iii
Introduction.....	1
What is Noise?	1
How Do We Measure Sound?.....	2
Field Measurement of Road Noise	5
Where Does Highway Noise Come From?.....	5
How Does Pavement Type Affect Traffic Noise?.....	6
What are the Federal and State Regulations and Policies Relevant to Traffic Noise?	7
How Does WSDOT Manage the Life of Pavements?.....	9
What is Quieter Pavement?.....	11
What Types of Quieter Pavements Are In Use Today?.....	11
How Have Quieter Pavements Performed?	11
WSDOT’s Experience With Quieter Pavements.....	11
Other State Experiences With Quieter Pavements	13
What are the Challenges in Using Quieter Pavements in Washington State?	16
Conclusions.....	18
Next Steps.....	19
References.....	21
Appendixes	
Appendix A Arizona Specification for Asphaltic Concrete Friction Course	27
Appendix B State Climate Information	29
Appendix C Scenario for Annualized Cost Comparison	37
Appendix D Quieter Pavement Research From Around the World.....	39

List of Tables

Table 1. Noise Levels Associated With Common Activities 2
Table 2. Arizona Noise Level Test Results 7
Table 3. FHWA Noise Abatement Criteria. 8
Table 4. HMA Average Overlay Life in Years 10
Table 5. Performance of OGFC at High Traffic Urban Freeway Locations 12
Table 6. Annualized Cost 13
Table 7. Pavement Noise, Lifespan, and Cost Comparison. 16
Table 8. Average Precipitation Rates for Cities in Washington and Arizona. 29

List of Figures

Figure 1. Effect of Adding Noise Sources (Hanson et al.). 3
Figure 2. Effect of Distance on a Point Noise Source (Hanson et al.). 3
Figure 3. Effect of Distance on a Line Noise Source Over a Paved Surface. 4
Figure 4. Pavement Condition Trend. 10
Figure 5. Results of Arizona DOT CPX Testing (Close Proximity Noise Testing). 14
Figure 6. Studded Tire Damage on OGFC in Washington State 18
Figure 7. Temperature and Precipitation Information for Seattle 30
Figure 8. Temperature and Precipitation Information for Phoenix 30
Figure 9. Temperature and Precipitation Information for Flagstaff. 31

Executive Summary

Highway noise negatively affects nearby residents. Noise issues have become a primary concern for many residents in our heavily traveled urban areas. Noise reducing technologies can have a positive impact on the quality of life of these residents. Historically, the most effective method of reducing traffic noise has been the use of noise barriers, including noise walls and noise berms. Noise barriers decrease noise from all sources: tire-pavement interaction, vehicle noise, and exhaust noise.

Interested and affected parties are political, social, and scientific: political leaders want intelligent use of state funds and good performance for the citizens; residents want relief from noise and drivers desire less splash and spray in rainy weather; transportation engineers want to balance safety, comfort and mobility, while maintaining pavement performance, including durability, skid resistance, structural condition, and smoothness.

Quieter Pavements in the form of asphalt Open Graded Friction Courses (OGFC) can reduce traffic noise and splash and spray from rainfall. These performance benefits come at a cost in durability, greatly reducing pavement life compared to traditional asphalt and concrete pavements. The benefit of noise reduction, and splash and spray reduction degrades over relatively short periods of time, reducing the effectiveness of the OGFC quieter pavement. Pavement lives of less than ten years, and as short as three to four years, have occurred with the use of OGFC quieter pavements in Washington's high traffic corridors. The duration of asphalt based quieter pavement in the USA and around the world tends to average between eight and 12 years. Compare this to an average pavement life of 16 years in western Washington and the loss of durability is clear. Under RCW47.05, WSDOT is instructed to follow lowest life cycle cost methods in pavement management. Less durable pavements do not meet this legislative direction.

Studded tire usage in Washington State is another complicating factor. Studded tires appear to rapidly damage quieter pavements, resulting in raveling and rutting. When OGFC was used on I-5 in Fife, the pavement rutted in as little as four years. States where the use of OGFC has been successful (Florida, Texas, Arizona, and California) do not experience extensive studded tire usage. Similarly, these states are southern, warm weather states; a clear advantage when placing a product that requires the existing pavement to have an 85°F surface temperature at the time of placement. Washington State urban pavements, placed at night to avoid traffic impacts, rarely reach this temperature during the available nighttime hours for paving (10:00 p.m. to 5:00 a.m.), even in summer. Other pavements and bridge decks reach such temperatures at night only on rare occasions, making placement of rubberized OGFC difficult or impossible at night.

Opportunities exist to try the newest OGFC designs in high traffic corridors in Washington State. WSDOT places experimental pavements as funding and projects permit, to try new designs that might increase performance: Past examples include designs for greater durability, increased resistance to studded tire wear, and new dowel bar retrofit alternatives. Locations are carefully selected to control as many variables as possible and to achieve results that are relevant. Experimental paving could include:

- new generation OGFC, with polymer modifiers and fibers;
- new aggregate gradations;
- new mix designs with greater voids and binder contents.

Unanswered questions about the long-term performance of OGFC in urban environments include:

- durability
- noise reduction
- splash and spray performance
- studded tire resistance
- installation challenges (night work, temperature restrictions, etc.)

A search is underway for appropriate test sites with possible installation in 2006.

Introduction

Pavements come in many shapes and material mixes. From the early years of cobblestones and bricks to present day stretches of roadway, pavements have generally become smoother, quieter, less expensive, and longer-lasting. The standard road surface today is a variation on Portland cement concrete (PCC) pavement and hot-mix asphalt (HMA) pavement.

Over the past 20 years, materials experts have evaluated different material mixes and application methods of PCC and HMA to reduce sound energy and make the existing traffic noise more palatable for residents and motorists. The success rates of their efforts depend largely on the specific weather, temperature, and tire types for each state or region that was evaluated. The following text discusses how noise is generated and some of the options and constraints for placing quieter pavement within Washington State.

The standard road surface used today in Washington and other states is a variation of either:

PCC – Portland Cement Concrete

HMA – Hot-Mix Asphalt

HMA pavements have an average statewide lifespan of up to 14.7 years, and an average lifespan of over 16 years in western Washington.

PCC pavements have an average statewide lifespan of up to 35 years.

What is Noise?

In the simplest terms, noise is any unwanted sound. The definition of unwanted sound is subjective, varying from person to person: one person's music is another person's noise. Different noises produce different reactions depending both on their intensity (how loud they are) and on their frequency distribution (also described as pitch, varying from low to high). Human hearing tends to be more sensitive to higher pitches of sound, like emergency sirens or tire squeal, and less sensitive to lower pitches, like the base notes on the stereo. At the same intensity of sound, a higher pitch can sound louder or more annoying than a lower pitch.

Tire noise on pavement produces a range of sound frequencies. When multiple vehicles pass by a listener, the individual frequencies tend to blend in the human ear, resulting in what many people describe as broad spectrum white noise. For some listeners, the white noise can be similar to the sound of rushing water in a river.

How Do We Measure Sound?

A logarithmic scale (for noise, this is referred to as the A-scale) is used to represent sound levels and is measured in decibels (dB). The curve that describes the A-scale roughly corresponds to the response of the human ear to sound. Studies have shown that when people make judgments about how noisy a source is that their judgments correspond quite well to the A-scale sound levels. The decibel scale ranges from 0 dBA, the threshold of human hearing, to 140 dBA where serious hearing damage can occur. The average human ear can only differentiate between two sound levels that are at least three dBA different in loudness. Table 1 represents this scale and some of the levels associated with various daily activities.

Table 1. Noise Levels Associated With Common Activities

Activity	Noise Level (dBA)
Threshold of pain	140
Jet flyover at 1000 feet	110
Gas lawnmower at three feet	100
Loud shout	90
Diesel truck at 50 feet	90
Motorcycle passing at 50 feet	85
Blender at three feet	85
Car traveling 60 mph passing at 50 feet	80
Heavy traffic at 300 feet	60
Normal conversation	60
Quiet living room	40

Traffic noise typically ranges between 55 and 80 decibels along a highway right of way line.

Because of the logarithmic decibel scale, a doubling of the noise sources only increases noise levels by three dBA. Figure 1 illustrates the effects of adding two noise sources. If the noise level from one source of sound (a blender) measured at 3 feet from the blender is 85 dBA, then the noise level from two blenders would be 88 dBA, and the noise level from three blenders would increase to 89.8 dBA.

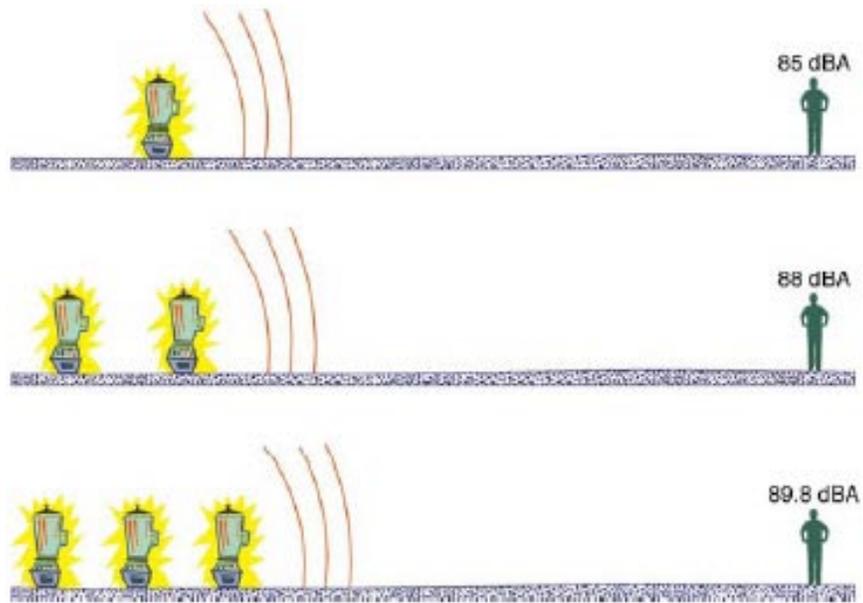


Figure 1. Effect of Adding Noise Sources (Hanson et al.)

For a single noise source, such as a blender, the noise is reduced by 6 dBA when the distance away from the source is doubled and is 9.5 dBA at three times the distance. Thus, if you have a blender that has a sound level of 85 dBA at 3 feet, when you move 6 feet away from the blender, the noise level would be 79 dBA, and if you move three times the distance (9 feet) away from the blender, the noise level would be 75.5 dBA. This is illustrated in Figure 2.

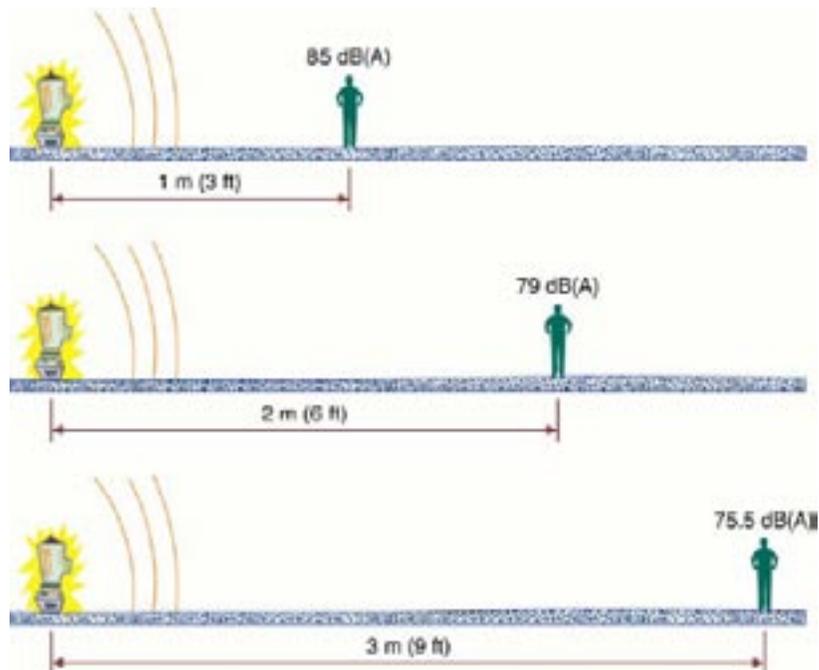


Figure 2. Effect of Distance on a Point Noise Source (Hanson et al.)

Roadway noise, however, acts in a different manner. As a vehicle passes by a point, the noise is reaching the point from all along the roadway or from each point where the vehicle was. As the distance from the noise source increases, the noise level decreases at a lower rate than from a single point noise source. For paved surfaces, the doubling of the distance would result in a 3-dBA reduction in the noise level. Thus, if a point 16 feet from the center of the noise source (the center of the lane) of the roadway has a noise level of 85 dBA, then a point 32 feet from the edge of the roadway would have a noise level of 82 dBA. This is illustrated in Figure 3.

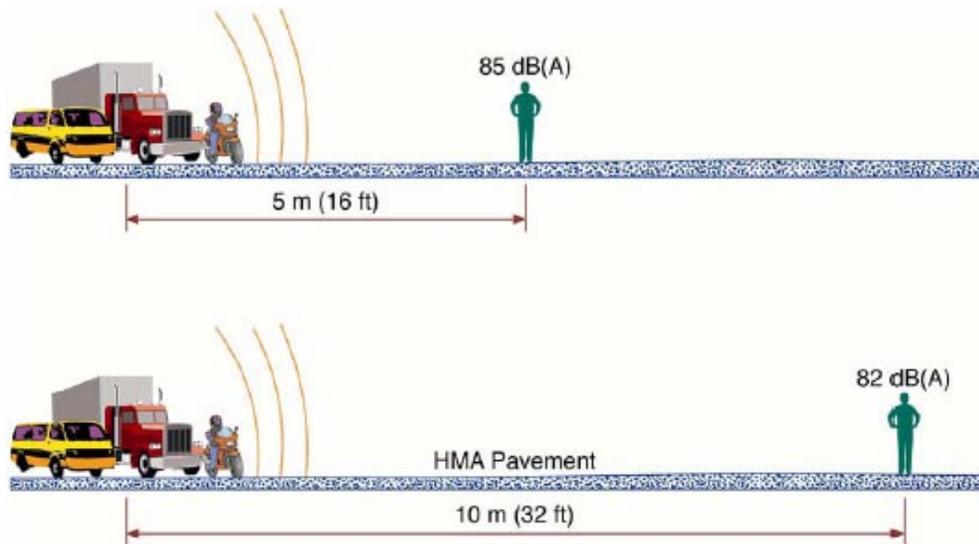


Figure 3. Effect of Distance on a Line Noise Source Over a Paved Surface

The amount of traffic noise depends on traffic volume, speed, and the type of vehicle. Generally, an increase in volume, speed, or vehicle size increases traffic noise levels. Vehicle noise is a combination of sounds from the engine, exhaust, and tires. Other conditions affecting traffic noise include defective mufflers, steep grades, terrain, vegetation, distance from the roadway, and shielding by barriers and buildings.

Field Measurement of Road Noise

Three methods commonly used for measuring pavement noise levels in the field are:

Statistical Pass-by Procedure — The statistical pass-by method consists of placing microphones at a defined height and distance from the vehicle path at the side of the roadway.

Single Vehicle Pass-by Method — With the single vehicle pass-by method, noise from cars and light trucks is typically measured at a specially designed test site. The vehicle approaches the site at a precise speed and gear. A sound level meter is set at a specified distance from the center of the travel path and captures the sound level of the vehicle as it passes.

Near-field Techniques — Near-field techniques, such as the close proximity method (CPX), measure sound pressure using microphones mounted on the vehicle near the vehicle tire.

Where Does Highway Noise Come From?

Highway traffic noise is generated from three main sources:

1. The contact-point between the tire and the road (tire/pavement noise).
2. The vehicle engine.
3. The exhaust system.

The tire/pavement noise accounts for 75 to 90 percent of the overall noise energy (Caltrans, 2003) when driving over 50 miles per hour.

The frequency and intensity of tire/road noise depends on a variety of factors:

- Roadway roughness
- Tire tread configuration
- Studded tires
- Roadway surface openings (voids)
- Joints in the PCC pavements
- Speed of traveling vehicles
- Size of tires (amount of rubber on the road)

According to Brennan et al., cars are quieter than medium trucks and multi-axle trucks, mainly due to fewer tires. There is about a 5.6 dBA increase from cars to dual-axle vehicles and another 5.6 dBA increase to multi-axle vehicles. This is supported by Kandahl (2003), where he notes that trucks are a louder source of noise, but since the traffic is primarily comprised of cars, this noise can be more disruptive because of the constant whine.

How Does Pavement Type Affect Traffic Noise?

Traffic noise varies depending on the pavement surface and a number of other factors, including:

- pavement texture (negative or positive)
- tire tread
- studded tire wear
- roadway surface openings (voids)
- joints in concrete pavements
- vehicle speed

“Negative texture” refers to small holes in the pavement that reduce noise.

“Positive texture” refers to small bumps sticking out of the pavement, which are not very effective in reducing noise.

Generally, HMA pavements tend to be quieter than PCC pavements and open graded friction course (OGFC) pavements tend to be quieter still. This is a dramatic generalization, since the performance for either HMA or PCC covers a wide range of noise generation, from moderately quiet to very loud. Arizona DOT measured various pavements for noise generation, including:

- Asphalt rubber-asphalt concrete friction courses (AR-ACFC, Arizona DOT’s version of OGFC).
- PCC pavements with various surface treatments, including:
 - Tined surfaces (PCC pavement that has been given a texture with a tining rake, similar to a garden leave rake).
 - Ground surfaces (PCC pavement ground to a smooth texture by a large diamond grinding machine).
 - Grooved surfaces (PCC pavement that has had grooves cut into it).

The results show that while the AR-ACFC are quieter overall than the PCC pavements, the differences vary considerably depending on location, with some PCC pavements being very close to the noise levels of the AR-ACFCs.

Table 2. Arizona Noise Level Test Results

Location	Surface Type	Construction Year	Mean dBA at 55 mph	Mean dBA at 65 mph
1: I-10 W of Phoenix	AR-ACFC	1994	94.6	97.2
	PCC, tined	1994	97.6	100.4
	AR-ACFC	1994	94.5	97.0
2: I-17 Phoenix	AR-ACFC	1994	92.7	95.5
	PCC, ground	1991	96.6	---
	AR-ACFC	1992	94.4	95.9
3: I-10 Tucson	PCC, ground	1989	96.7	99.0
	PCC, ground	1983	98.2	100.8
4: I-19 Tucson	AR-ACFC	1992	92.3	94.7
	AR-ACFC	1988	93.2	95.6
	PCC, grooved	1988	95.2	97.5

Pavement type influences the generation of tire/pavement noise, but noise reductions vary considerably for the same type of pavement built in different locations. The California Department of Transportation (CalTrans) has measured similar noise levels for a wide variety of pavement types, including OGFC, rubber modified HMA and PCC pavements with longitudinal tining.

What are the Federal and State Regulations and Policies Relevant to Traffic Noise?

Federal Regulation (23CFR772) and State Noise Policy and Procedures require noise evaluations for Washington’s highways under three main project conditions:

1. A new roadway is constructed,
2. Additional through-lanes are added to an existing roadway,
3. The existing roadway is significantly realigned either horizontally or vertically.

When WSDOT, cities, and counties construct transportation projects that cover any of the three conditions, they are called “Type 1” noise projects. Noise impacts may also be considered when the land surrounding the roadway is substantially altered, increasing exposure to the roadway.

Noise impacts are evaluated using noise regulations and guidelines provided by the Federal Highway Administration (FHWA), U.S. Department of Transportation (USDOT), and WSDOT. For Type I projects, traffic noise impacts occur when predicted time averaged sound levels (LAeq(h)) approach or exceed the noise abatement criteria (NAC) established by the FHWA, or substantially exceed existing sound levels (U.S. Department of Transportation, 1973, Noise Abatement Council). The term “substantially exceed” is defined by WSDOT as an increase of 10 dBA or more.

The FHWA noise abatement criteria specify exterior LAeq(h) noise levels for various land activity categories (Table 2). For receptors where serenity and quiet are of extraordinary significance, the noise criterion is 57 dBA. For residences, parks, schools, churches, and similar areas, the noise criterion is 67 dBA. For developed lands, the noise criterion is 72 dBA. WSDOT considers a noise impact to occur if predicted LAeq(h) noise levels approach within 1 dBA of the noise abatement criteria in Table 3.

Table 3. FHWA Noise Abatement Criteria

Activity Category	Leq(h) (dBA)	Description of Activity Category
A	57 (exterior)	Lands on which serenity and quiet are of extraordinary significance and serve an important public need, and where preserving these qualities is essential if the area is to continue to serve its intended purpose.
B	67 (exterior)	Picnic areas, recreation areas, playgrounds, active sports areas, parks, residences, motels, hotels, schools, churches, libraries, and hospitals.
C	72 (exterior)	Developed lands, properties, or activities not included in Categories A or B above.
D	---	Undeveloped lands.
E	52 (interior)	Residences, motels, hotels, public meeting rooms, schools, churches, libraries, hospitals, and auditoriums.
Source: U.S. Department of Transportation, 1982.		

How Does WSDOT Manage the Life of Pavements?

Section 47.05 of the Revised Code of Washington (RCW), titled “Priority Programming for Highway Development,” directs WSDOT to manage a preservation program that:

“...consists of those investments necessary to preserve the existing state highway system and to restore existing safety features, giving consideration to lowest life cycle costing. The preservation program must require use of the most cost-effective pavement surfaces, considering:

- (a) Life-cycle cost analysis;
- (b) Traffic volume;
- (c) Subgrade soil conditions;
- (d) Environmental and weather conditions;
- (e) Materials available; and
- (f) Construction factors”

“Pavement Life” is a term used to describe the length of time before a pavement surface needs to be replaced.

To manage pavements under the lowest life cycle cost, WSDOT operates the Washington State Pavement Management System (WSPMS), one of the most sophisticated pavement management systems in the world. The WSPMS thoroughly measures pavement condition on all state highways annually. Pavement is rated on:

- Smoothness, using the International Roughness Index.
- Rutting, using a 12-foot-wide scanning laser.
- Structural condition, using high speed digital images viewed and rated by a team of trained pavement rating personnel.

Applying the lowest life cycle cost concept in conjunction with the WSPMS resulted in a marked improvement of pavement condition, reducing pavements in poor and very poor condition from 50 percent in 1971 to less than 10 percent in 2003 (Figure 4). Pavement management through the WSPMS and the Preservation Program Model significantly improved the condition of the pavements over the last 30 years. Enhancements in design and construction have also improved pavement condition and extended pavement life.

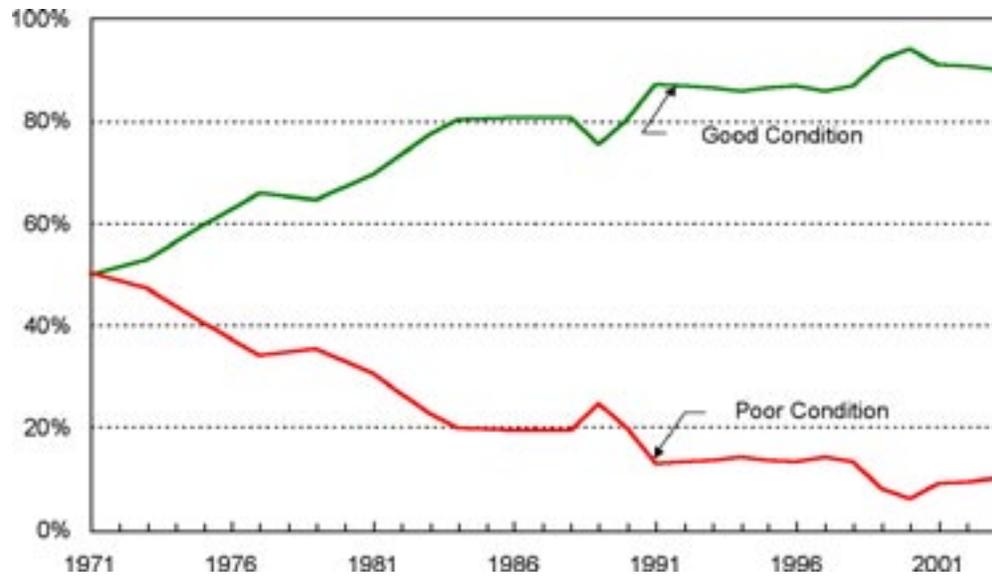


Figure 4. Pavement Condition Trend

Pavement durability is a critical element in the life cycle cost: longer-lasting pavements with the same initial cost have lower life cycle costs. Newly constructed HMA pavements in western Washington are expected to have a 16-year pavement life, based on HMA performance from the WSPMS. HMA pavement durability has steadily increased over time (Table 4). Newly constructed PCC pavements are expected to have 50-year pavement lives, based on past performance in the WSPMS and new designs for PCC pavement. Changes in pavement design that decrease the average pavement life, conflict with the legislative mandate in RCW 47.05.

Table 4. HMA Average Overlay Life in Years

Year	Eastern	Western	Statewide
1997	10.7	14.6	12.9
2000	10.8	15.8	14.1
2003	11.3	16.5	14.7

Washington State’s highway pavements typically outperform similar pavements in many other states. High quality local aggregates are to credit for this accomplishment, as is a 30-year focus on pavement quality and lowest life cycle cost management. New pavement designs must provide comparable pavement lives if they are to be preserved under existing funding. Any reduction in pavement live, or increase in life cycle cost, would strain an already under-funded pavement preservation program.

What is Quieter Pavement?

Quieter pavement reduces noise from tire/pavement interaction compared to traditional pavements. Noise reduction usually comes from the type of surface texture used on the pavement.

What Types of Quieter Pavements Are In Use Today?

The majority of quieter pavement designs use a “negative texture,” and the most common of these is the open graded friction courses (OGFC). OGFC use small holes, or air voids, in the pavement to provide a sound absorbing negative texture. OGFC can be made with conventional liquid asphalts or with polymer-modified asphalts, including rubberized asphalts. Rubberized OGFC use finely ground rubber from used tires to modify the asphalt binder in the pavement mixture.

These OGFC varieties differ from traditional dense-grade HMA by having much higher air voids. Typical dense-grade HMA has air voids that begin at 8 percent and decrease over the life of the pavement to approximately four percent. OGFC start with air voids from 10 to 22 percent and see little decrease over the life of the pavement. Most modern OGFC have air voids in from 15 to 22 percent.

How Have Quieter Pavements Performed?

WSDOT's Experience With Quieter Pavements

Quieter pavements perform poorly on western Washington's urban freeways. Quieter pavement lives are only one-third to one-half that of comparable dense-grade HMA. Quieter pavements perform even worse when compared to PCC pavements. PCC is most commonly found in urban corridors because of its durability: durable pavements require less rehabilitation and reduce construction impacts to the traveling public.

WSDOT built three relevant projects on I-5 in the 1990s that used quieter pavement as shown in Table 5. These projects rutted rapidly and performed very poorly compared to the dense-grade HMA. The early failure was due to a type of rutting called “raveling,” which refers to the physical loss of material from the surface of the pavement. Rutting requires rehabilitation, because rutted pavements trap water and increase the risk of hydroplaning. WSDOT requires pavements to be rehabilitated when rutting is greater than ten millimeters in depth. Funding constraints prevented repairs to occur in a timely manner for the I-5 projects: poor performance was not expected and funding was not available for immediate replacement. Table 5 lists the projects and the time it took to reach a 10-millimeter rut depth. The roadways were repaved at a later date because of limited funding.

Table 5. Performance of OGFC at High Traffic Urban Freeway Locations

State Route	Year	Contract	Location	Year Repaved	Time to 10 ml Rut Depth (Years)	ADT	Percent Trucks
5 (Fife)	1985	2554	MP 135.54 to MP 139.50	1994	4 (NB) 6 (SB)	170,000	9
5 (Tumwater)	1991	3939	MP 101.23 to MP 102.69	2001	7	74,000	12
5 (Vancouver)	1986	3044	MP 0.27 to MP 2.42	1997	8	100,200	8
Note: NB = northbound SB = southbound ADT = average daily traffic							

The average daily traffic for these three projects reflects traffic volumes similar to urban freeways that might receive treatment with quieter pavements made from OGFC. Performance for these OGFC ranged from four years to eight years before needing replacement. Contrast this performance with dense-graded HMA that has an average pavement life of 16 years and consider the cost impacts. The OGFC poor performance is compounded by its increased life cycle cost.

The durability of OGFC pavements on Washington's urban freeways has been poor, and because of the short pavement life, the life cycle cost is correspondingly high.

Table 6 below compares the annualized costs, for both agency (WSDOT) and user (traffic delays due to replacing the pavement), between OGFC of durability ranging from six to ten years, to dense-grade HMA with a pavement life of 16 years. Annualized cost increases for OGFC range from nearly triple that of dense-grade HMA to over 1_ times the dense-grade pavement. In a program with persistent funding challenges, such marked decreases in pavement life cannot be absorbed or maintained.

Table 6. Annualized Cost

Overlay Type	Expected Life	Annualized Cost		
		Agency	User	Total
OGFC	6 year	\$26,730	\$ 263,860	\$ 290,590
	7 year	\$23,340	\$ 254,410	\$ 277,750
	8 year	\$20,820	\$ 213,710	\$ 234,530
	9 year	\$18,869	\$ 183,650	\$ 202,519
	10 year	\$17,261	\$ 149,340	\$ 166,601
HMA	16 year	\$12,044	\$ 94,200	\$ 106,244

Note: The annualized total cost for PCC and HMA for high traffic urban reconstruction projects of this type has been found to be similar from other life cycle cost analyses; hence the cost difference for OGFC and PCC can be assumed to be similar to that for OGFC and HMA for reconstruction projects. See Appendix C for details on these calculations.

RCW 47.05 requires considering the lowest life cycle cost, a condition which previous uses of quieter pavements in Washington State have failed to meet with their short lives and their excessive life cycle costs.

Other State Experiences With Quieter Pavements

Texas, California, Florida, and Arizona lead the nation in the placement of quieter pavements (with or without rubberized and non-rubberized asphalt binder). Arizona, in particular, is a leader in placing and extolling the virtues of quieter pavements, using extensive quantities of rubberized OGFC. Arizona and California use rubberized OGFCs to reduce noise, while Texas concentrates on the OGFC's ability to reduce splash and spray.

Three important performance factors must be considered for these pavements:

- Noise reduction.
- Durability of the noise reduction (does it change over time?).
- Durability of the pavement (expressed by the important engineering properties of friction, smoothness and structural condition).

Noise Reduction: California (Caltrans) and Arizona (ADOT) both report pavement noise reductions for their quieter pavement programs compared to traditional pavement. Arizona reports the largest noise reductions, in the range of 3 to 7 dBA. California reports more modest noise reductions, in the range of 1 to 5 dBA. Importantly, both states report widely overlapping ranges of noise reduction, for both quieter pavements and traditional

pavements. Pavement noise reduction is not uniform for any given pavement design, although the general trends noted above (most HMA pavements being generally quieter than most PCC pavements) remain the same. New designs for PCC can equal the noise reductions of both dense-grade HMA and many quieter pavements.

Durability of the Noise Reduction: To be allowed as environmental mitigation, noise reductions achieved with quieter pavements must remain over the lifetime of the pavement. If a pavement is initially quiet but then rapidly increases in noise level, the gain from the initial noise reduction is lost and the residents realize no benefit. Noise walls are durable and permanent; quieter pavements are not. Arizona DOT studies show that quieter pavement noise reductions degrade over time. The pavement may function for many years, but the noise reduction compared to other pavement types is lost over time.

Arizona DOT performed research on their AR-ACFC (Scofield, 2002) with the Close-Proximity Method (CPX) and California DOT's noise intensity measurement system. Testing was performed on traffic traveling at 60 mph. The age of the AR-ACFC pavements ranged in age from three to 12 years and the noise levels varied from 94 to 101 dBA. The results show an increase in noise of approximately 7 dBA over a 10-year period (Figure 5).

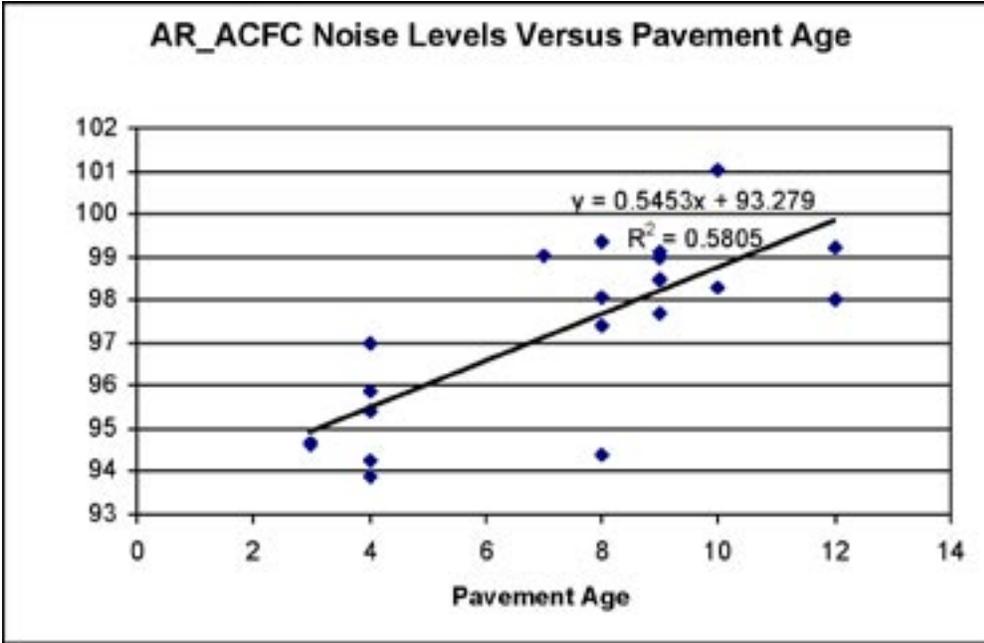


Figure 5. Results of Arizona DOT CPX Testing (Close Proximity Noise Testing)

These results show increasing noise over time, negating the early noise reducing. At year four, the study and graph show five quieter pavements had noise ranges varying from a little less than 94 dBA to nearly 97 dBA, a range of over three dBA for the same type and age of pavement.

Pavement Durability: It is important to evaluate pavement durability because pavements that are less durable need to be replaced more frequently, which increases highway maintenance costs. All pavements degrade over time, though not at the same rate and any reduction in pavement durability severely impacts our ability to manage pavements effectively. The “pavement life” for quieter pavements used by the Arizona DOT is much shorter than the pavement life of a typical asphalt pavement in western Washington. Western Washington pavements last an average of 14 to 16.5 years (depending on the region), which is significantly higher than the pavement lives of quieter pavements used by the Arizona DOT.

Appendix D contains capsule results from quieter pavement studies in the U.S. and around the world. The findings are remarkably similar: quieter pavements offer a small range of noise reduction (3 to 7 dB) but at a cost in durability and shorter pavement lives (eight to 12 years). Shorter pavement lives correlate to an increase in life cycle costs, compared to traditional pavements. These shorter pavement lives experienced worldwide for quieter pavement occur even though none of the states or countries mentioned the use of studded tires.

The following table illustrates a basic comparison according to pavement type, initial and long-term noise characteristics, pavement lifespan, and long-term pavement costs.

Table 7. Pavement Noise, Lifespan, and Cost Comparison

Pavement Option	Initial Noise – New Pavement			Long-Term Noise			Pavement Lifespan (life to removal)	Long-Term Pavement Cost
	Sound Quantity (decibel change from average)	Dominant Frequency or Pitch	Rating	Sound Quantity (decibel change from average)	Dominant Frequency or Pitch	Rating		
Open Graded Friction Course	-2 dB*	lower frequencies	Good	0 to -2 dB	Middle frequencies	Fair/Poor	Short (4 to 10 years)	High
Dense-Graded Asphalt	-1 dB*	lower frequencies	Good	0 to -1 dB	Middle frequencies	Fair	Medium (14 to 18 years)	Moderate
Concrete	0 to +2 dB*	Depends on surface finish	Fair	Depends on studded tire damage	Higher frequencies	Poor	Long (40 to 50 years)	Moderate
Rubberized Asphalt	(specific dB comparison unavailable)	lower frequencies	Good	Unknown	Middle frequencies	Fair	Nighttime temperatures restrict material placement	High

What are the Challenges in Using Quieter Pavements in Washington State?

The most successful states in placing quieter pavements, rubberized quieter pavements, in particular, are all on the southern tier of the United States. Arizona, California, Texas, and Florida are Sunbelt states, tending to be significantly warmer and drier than Washington State. This affects constructing quieter pavement in three important ways:

Climate: Sunbelt states experience higher surface temperatures in existing pavements, increasing the opportunities for placing rubberized quieter pavements.

Arizona DOT specifications (see Appendix A) for rubberized OGFC require that the existing pavement surface be at or above 85°F before paving. Urban paving in western Washington is typically done at night and very rarely is the existing pavement surface above 75°F throughout the night, even in the warmest of summers (see Appendix B for additional climate comparison). Given that the climate in western Washington does not allow the pavement surface temperature to reach 85°F at night, daytime paving of rubberized OGFC would be the only remaining option. However, western Washington’s urban traffic prohibits daytime paving, as closing major urban freeways during the day to pave results in catastrophic traffic backups. Closing entire sections of urban freeways on weekends has been done successfully, but

only when the work can proceed around the clock, 24 hours a day. Notable examples include SR 520 across the floating bridge and I-405 from Bellevue to Renton. Closing these freeway sections during the day would result in unacceptable traffic backups.

Durability: The pavement life for quieter pavements has proven to be much lower than traditional pavements. Traditional pavement life in western Washington is between 14 to 16.5 years. The Arizona DOT's website states that their quieter pavements have pavement lives of 10 years, much lower than WSDOT's pavement life. A decrease in pavement life of this magnitude would require more funds to support the preservation of the state's pavements. If these funds were not found, the condition of pavements in the state would dramatically decrease.

Studded Tire Usage: Motorists in Washington State take advantage of their ability to use studded tires to help deal with winter weather (snow, ice, freezing rain). In contrast, the southern states mentioned above, that use quieter pavements, either ban studded tires or see no significant studded tire use. Quieter pavements, respond poorly to studded tires, because of the small holes, or air voids. As described above, due to both studded tires and heavy traffic, the quieter pavement placed on I-5 in Fife had a pavement life of five to six years, one third as long as typical western Washington pavements.

Studded tires act as small milling machines on any type of pavement. The stud is many times harder than the pavement and each revolution of a studded tire wears away small pieces of the pavement. Traditional pavements (HMA and PCC) have a higher resistance to this wear, although erosion still occurs. What differentiates traditional from quieter pavements is the percentage of air voids or holes. The more holes in the pavement, the more noise is absorbed, however, air has no strength. And as air voids in pavement increase, pavement strength decreases. With high air voids and lower strength, the quieter pavements cannot resist the grinding action of studded tires. As noted, on I-5 in Fife, the quieter pavement eroded in as little as five years, because of high traffic volumes and studded tires.



Figure 6. Studded Tire Damage on OGFC in Washington State

Conclusions

Quieter pavements (OGFC) can potentially reduce traffic noise. Initial noise reductions average between 3 and 5 dB when compared to the old pavement; how these noise reductions degrade over time is uncertain. In Washington State, on high traffic urban highways, quieter pavements performed poorly, with pavement lives ranging from four to ten years. Standard western Washington pavements average 16-year lives in similar locations and under similar or more strenuous conditions. Large reductions in pavement life result in significant increases in life cycle cost, a major factor in managing the Washington State Highway Preservation Program.

Texas, Florida, Arizona, and California are the recognized leaders in quieter pavements. These states have several advantages over Washington: none of the states have any significant studded tire use and all have climates with high average temperatures in summer. Studded tires are the major cause of OGFC deterioration in Washington State. Rubber modified OGFC requires 85°F surface temperatures at time of placement, conditions easily found in southern states, but rarely found in western Washington's high traffic urban areas, particularly at night when urban asphalt paving is done to avoid traffic impacts.

Next Steps

Pavement engineers continue to improve the design and durability of pavement to meet new challenges. Pavement designers traditionally try to enhance:

- friction characteristics (for safety),
- rutting resistance (for safety and durability), and
- structural performance (for durability) in highway pavements.

These characteristics require tradeoffs in HMA: high rutting resistance means less durable pavements, while increasing durability can result in early rutting failure. As in all engineering, finding the best balance of pavement characteristics is the goal. New desirable pavement characteristics (noise reduction, reduction of splash and spray) require both new designs and new tradeoffs.

In Washington State, the continued use of studded tires limits the performance of quieter pavements. Newer designs, using fibers and polymer modifiers might better resist studded tire wear, but the high air voids in these designs will limit their durability. Given the newest designs, trial pavements are worth constructing in western Washington, so that practical application and performance can be monitored.

The following steps should be taken to more closely examine the performance quieter pavements:

1. Conduct a more extensive literature study in the use of OGFC and other noise reducing pavements. The study should highlight:
 - National and international quieter pavement performance.
 - Special needs based on the climate in Washington State.
 - The effect of studded tires on quieter pavements.
 - Implications for use in Washington State.
2. Research locations for trial projects that would use experimental pavement treatments for noise reduction. Design, installation and evaluation of experimental noise-reducing pavements in urban, high traffic volume locations should be a priority. Locations should be carefully selected to control as many variables as possible and to produce relevant results. Experimental paving could include:
 - Next generation OGFC with polymer modifiers and fibers.
 - New aggregate gradations.
 - Advanced mix designs with greater voids and greater binder contents.

3. Establish a program to measure pavement noise using the sound intensity (close proximity) method. This program would require capital and operating funds. Capital expenses include sound intensity measuring equipment, tires, and a vehicle to install the equipment on. Operating expenses include vehicle operators and staff necessary to reduce, analyze, and track the generated sound intensity data.
4. Closely monitor the efforts being carried out by Texas, California, Florida, and Arizona to install quieter pavements. WSDOT already leads a pooled fund effort, the State Pavement Technology Consortium (SPTC), which studies common interests in pavements. SPTC members include California (Caltrans), Texas (TxDOT), Minnesota (MnDOT), and Washington (WSDOT) and are in the process of adding Florida (FDOT). The next meeting of the SPTC is planned in Arizona to examine Arizona DOT's work on quieter pavements.

References

- Anfosso-Lédée, F., and M.-T. Do. Geometric Descriptors of Road Surface Texture in Relation to Tire-Road Noise. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1806, Transportation Research Board, National Research Council, Washington, D.C., 2002, pp. 160-167.
- Arizona Department of Transportation (ADOT). “‘Quiet Pavement’ Project Underway,” ADOT website, <http://quietroads.com/> (accessed October 28, 2004).
- Baker, S. L. Designers Look for Ways to Reduce Noise. *Seattle Daily Journal of Commerce: Design 95*. <http://www.djc.com/special/design95/10002599.htm> (accessed August 25, 2004).
- Balmer, G. G. The Significance of Pavement Texture. Report FHWA-RD-75-12. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1975.
- Bérenghier, M. C., and J. F. Hamet. Acoustic Classification of Road Pavements: Ranking Differences Due to Distance From the Road. *Heavy Vehicle Systems, International Journal of Vehicle Design*, v. 6, no. 1-4, 1999, pp. 13-27.
- Bishop, M. C., and M. F. Oliver. Open Graded Friction Course Pavements. British Columbia Ministry of Transportation and Highways, Victoria, B.C., 2001.
- Brennan, M. J., A. M. Kavanagh, and J. N. Sheahan. Case Studies of a Low-Noise Road Surface. *International Journal of Pavement Engineering*, v. 2, no. 2, 2001, pp. 121-134.
- California Department of Transportation. Sound Engineering: Innovation in Pavements. *California Transportation Journal*, Jan-Mar 2003, pp. 34-37. http://www.dot.ca.gov/dist07/aboutdist7/pubs/journals/jan_mar_2003/janmar03.pdf (accessed August 25, 2004).
- Chalupnik, J. D. and D. S. Anderson. Acoustic Characteristics of Roadway Surfaces. Report WA-RD-129.1. Washington State Department of Transportation, 1987.
- Chandler, J. W. E., S. M. Phillips, P. G. Roe, and H. E. Viner. Quieter Concrete Roads – Construction, Texture, Skid Resistance and Noise. Project Report PR IP/121/00. Transport Research Laboratory (TRL), Berkshire, U.K., 2003.
- Choubane, B., G. A. Sholar, J. A. Musselman, and G. C. Page. Ten-Year Performance Evaluation of Asphalt-Rubber Surface Mixes. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1681,

Transportation Research Board, National Research Council, Washington, D.C., 1999, pp. 10-18.

Colorado Asphalt Pavement Association. Tire Pavement Noise: The Influence of Pavement Type on Noise Wall Design. Colorado Asphalt Pavement Association, Englewood, CO, 1999.

Colorado Department of Transportation. Highway Traffic Noise: Assessment and Abatement. Colorado Department of Transportation, 2004. <http://www.c470.info/NoiseBrochure.pdf> (accessed September 13, 2004).

Dash, D., C. Bryce, J. Moran, and S. Samuels. Road Trial of a Low-Noise Concrete Pavement with Exposed Aggregate Surfacing. *Road and Transport Research*, v. 11, no. 1, 2002, pp. 6-21.

Federal Highway Administration (FHWA). Highway Noise Fundamentals, Noise Fundamentals Training Document. US Department of Transportation, September 1980.

Fickes, M. The Asphalt Rubber Phenomenon: When Asphalt Rubber Silenced Road Noise on an Arizona Freeway, the Public Demanded More. *Hot Mix Asphalt Technology*, v. 8, no. 4, 2003, pp. 20-23.

Glazier, G., and S. Samuels. Effects of Road Surface Texture on Traffic and Vehicle Noise. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1312, Transportation Research Board, National Research Council, Washington, D.C., 1991, pp. 141-144.

Hamet, J.-F., and P. Klein. Road Texture and Tire Noise. Institut National de Recherche sur les Transports et leur Sécurité (INRETS). http://www.inrets.fr/ur/lte/publications/publications-pdf/web-hamet/in00_674.pdf (accessed September 13, 2004).

Hanson, D. I., and R. S. James. Colorado DOT Tire/Pavement Noise Study. Report CDOT-DTD-R-2004-5. Colorado Department of Transportation, 2004. <http://www.dot.state.co.us/publications/PDFFiles/tirenoise.pdf> (accessed September 13, 2004).

Harmelink, D. S. Using Ground Tire Rubber in Hot Mix Asphalt Pavements. Report No. CDOT-DTD-R-99-9. Colorado Department of Transportation. September 1999.

Heerkens, J. C. P. Open Graded Rubberized Asphalt for Traffic Noise Reduction on Urban Areas. The Netherlands, 1989.

Henderson, M. P., and S. A. Kalevela. A Comparison of Traffic Noise from Asphalt Rubber Asphalt Concrete Friction Courses (ARACFC) and Portland Cement Concrete Pavements (PCCP). Report No. FHWA-AZ-96-433. February 1996.

Herman, L. A., and M. J. Ambroziak. Effects of Pavement Type on Traffic Noise Levels. Ohio Research Institute for Transportation and the Environment, Athens, OH, 2000.

Hicks, G. R., and J. A. Epps. Life Cycle Cost Analysis of Asphalt-Rubber Paving Materials. First International Conference World of Asphalt Pavements, 2000.

Hofman, R., and J. van der Kooij. Results from the Dutch Noise Innovation Program Road Traffic (IPG) and Roads to the Future Program (WnT). In Inter-Noise 2003: 32nd International Congress and Exposition on Noise Control Engineering, Seogwipo, Korea, August 25-28, 2003. http://www.informex.info/IPG___WnT_results_-_Inter-Noise_2003_ppr.pdf (accessed September 13, 2004).

Hong Kong Special Administrative Region, Highways Department. Guidance Notes on Noise Reducing Road Surfacing. Publication RD/GN/011/B. The Government of the Hong Kong Special Administrative Region, Highways Department, Research & Development Division, 2001. http://www.hyd.gov.hk/eng/public/publications/guidance_notes/pdf/gn011b.pdf (accessed September 13, 2004).

Huber, G. Performance Survey on Open-Graded Friction Course Mixes. NCHRP Synthesis 284. Transportation Research Board, National Research Council, Washington, D.C., 2000.

Illingworth & Rodkin, Inc. I-80 Davis OGAC Pavement Noise Study: Traffic Noise Levels Associated with an Aging Open Grade Asphalt Concrete Overlay. California Department of Transportation, 2002. <http://www.dot.ca.gov/hq/env/noise/> (accessed September 13, 2004).

International Organization for Standardization. Measurement of the Influence of Road Surfaces on Traffic Noise – Part 1, Statistical Pass-by Method 11819-1. 1997a.

International Organization for Standardization. Measurement of the Influence of Road Surfaces on Traffic Noise – Part 2, Close-Proximity Method ISO Standard 11819-2. 1997b.

Kandahl, P. S. Asphalt Pavements Mitigate Tire/Pavement Noise. *Hot Mix Asphalt Technology*, v. 9, no. 2, 2004, pp. 22-31.

Kandahl, P. S. Design, Construction, and Maintenance of Open-Graded Asphalt Friction Courses. Information Series 115. National Asphalt Pavement Association, Lanham, MD, 2002.

Kandahl, P. S. How Asphalt Pavement Mitigate Tire-Pavement Noise. *Better Roads*, v. 73, no. 11, 2003, pp. s16-s22.

- Kandahl, P. S., and R. B. Mallick. Design of New-Generation Open-Graded Friction Courses. NCAT Report 99-3. National Center for Asphalt Technology, Auburn, AL, 1999. <http://www.eng.auburn.edu/center/ncat/reports/rep99-3.pdf> (accessed September 13, 2004).
- Kandahl, P. S., and R. B. Mallick. Open-Graded Friction Course: State of the Practice. Transportation Research Circular E-C005. Transportation Research Board, National Research Council, Washington D.C., 1998. <http://gulliver.TransportationResearchBoard.org/publications/circulars/ec005.pdf> (accessed September 13, 2004).
- Kuettel, DA; Sontag, RC; Crovetti, JA; Becker, Y; Jaeckel, JR; Satanovsky, A. Noise and Texture on PCC Pavements – Results of a Multi-State Study. Wisconsin Department of Transportation, 2000. <http://www.dot.wisconsin.gov/library/research/docs/finalreports/45-91noiseandtexture-f.pdf> (accessed September 13, 2004).
- Kay, R. A., and J. K. Stephens. Porous Friction Courses and Roadway Surface Noise, Implementation Package 74-11. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 1975.
- Kuennen, T. Asphalt Rubber Makes a Quiet Comeback. Better Roads, May 2004.
- Lee, Cynthia S.Y., and Gregg G. Fleming. Measurement of Highway-Related Noise, FHWA-PD-96-046. May, 1996.
- Livingston, J. and K. Anderson. Rubber Modified and PBA-6 Asphalt Binder Pavements: SR 5, Lewis County Line to SR 12. Report WA-RD-347.1. Washington State Department of Transportation, 1994.
- Mallick, R. B., P. S. Kandahl, L. A. Cooley, Jr., and D. E. Watson. Design, Construction, and Performance of New-Generation Open-Graded Friction Courses. Journal of the Association of Asphalt Paving Technologists, v. 69, 2000, pp. 391-423. (2000a)
- Mallick, R.B., P. S. Kandahl, L. A. Cooley, Jr., and D. E. Watson Design, Construction, and Performance of New-Generation Open-Graded Friction Courses. NCAT Report 2000-01. National Center for Asphalt Technology, Auburn, AL, 2000. (2000b). <http://www.eng.auburn.edu/center/ncat/reports/rep00-01.pdf> (accessed September 13, 2004).
- McNerny, M. T., B. J. Landsberger, S. Burcsak, J. DeMoss, and W. H. Yeo. Feasibility of Using Quiet Pavement Technology to Attenuate Traffic Noise in Texas. Texas Department of Transportation, 2001. http://www.utexas.edu/research/ctr/pdf_reports/2957_3.pdf (accessed September 13, 2004).
- McNerny, M. T., B. J. Landsberger, T. Turen, and A. Pandelides. Comparative Field Measurements of Tire/Pavement Noise of Selected Texas Pavements. Texas Department of Transportation, 2000. http://www.utexas.edu/research/ctr/pdf_reports/2957_2.pdf (accessed September 13, 2004).

- Miller, R. W., and R. A. Brown. Performance of Open-Graded Friction Courses. Research Report 58. New York State Department of Transportation, Engineering Research and Development Bureau, 1978.
- Newcomb, D., and L. Scofield. Quiet Pavements Raise the Roof in Europe. *HMAT: Hot Mix Asphalt Technology*, v. 9, no. 5, 2004, pp. 22-28.
- Olek, J., W. J. Weiss, and R. Garcia-Villareal. Relating Surface Texture of Rigid Pavement with Noise and Skid Resistance. Report SQDH 2004-1. Purdue University, West Lafayette, IN, 2004. [http://widget.ecn.purdue.edu/~sqdh/ Select 'Publications.'](http://widget.ecn.purdue.edu/~sqdh/Select%20Publications.) (accessed on September 13, 2004).
- Oshino, Y., and H. Tachibana. Relationships Between Road Texture and Tire/Road Noise. In *Noise-Con 96: Proceedings of the 1996 National Conference on Noise Control Engineering*, Seattle, WA, 1996, v. 1, pp. 67-72.
- Papagiannakis, A. T. and T. J. Loughheed. A Review of Crumb-Rubber Modified Asphalt Concrete Technology. Report WA-RD-379.1. Washington State Department of Transportation, 1995.
- Phillips, S. Determining the Performance of Quieter Road Surfaces. *Transport: Proceedings of the Institution of Civil Engineers*, v. 153, no. 2, 2002, pp. 111-120.
- Pierce, L. M. Rubber Modified and Performance Based Asphalt Binder Pavements, I-5 Nisqually River to Gravelly Lake. Report WA-RD-407.1. Washington State Department of Transportation, 1996.
- Raaberg, J., B. Schmidt, and H. Bendtsen. Technical Performance and Long-Term Noise Reduction of Porous Asphalt Pavements. Road Directorate, Danish Road Institute, 2001.
- Rubber Pavements Association. Asphalt-Rubber/Rubberized Asphalt: There is a Difference! <http://www.rubberpavements.org/library/difference.asp> (accessed November 16, 2004).
- Sandberg, U. Low Noise Road Surfaces – A State-of-the-Art Review. VTI Report 323. Swedish National Road and Transport Research Institute, 1999.
- Sandberg, U. Tyre/Road Noise – Myths and Realities. VTI Report 345. Swedish National Road and Transport Research Institute, 2001. <http://www.vti.se/pdf/reports/S345.pdf> (accessed September 13, 2004).
- Sandberg, U. and Jerzy A. Easement. Tyre/Road Noise Reference Book, Informex, 2002.
- Scofield, L. A. The History, Development, and Performance of Asphalt Rubber at ADOT. Report AZ-SP-8902. Arizona Department of Transportation. December 1989.
- Scofield, L. A. Preliminary Pavement Noise Research Results. Arizona Department of Transportation. December 2002.

Sebaaly, P. E., G. M. Bazi, and Y. Vivekanathan. Evaluation of New Pavement Technologies in Nevada. Nevada Department of Transportation. March 2003.

Smith, H. A. Performance Characteristics of Open-Graded Friction Courses. NCHRP Synthesis 180. Transportation Research Board, National Research Council, Washington, D.C., 1992.

Stephens, J. E., J. M. Mahoney, and C. E. Dougan. Early Distress in Open-Graded Friction Course. New England Transportation Consortium, Storrs, CT, 1999.

Wakefield Acoustics Ltd. Open-Graded Asphalt and Superpave Pavements: Assessment of Traffic Noise Reduction Effects. British Columbia Ministry of Transportation and Highways, Victoria, B.C., 2000.

Watts, G. R., S. N. Chandler-Wilde, P. A. Morgan, I. D. Richardson, and C. R. Ross. The Combined Effects of Porous Asphalt Surfacing and Barriers on Traffic Noise. In *Inter-Noise 96: Proceedings of Inter-Noise 96*. Institute of Acoustics, St. Albans, U.K., 1996, pp. 3103-3107.

Way, G. OGFC Meets CRM: Where the Rubber Meets the Rubber. Arizona Department of Transportation, 1998. <http://www.rubberpavements.org/library/crm.asp> (accessed November 1, 2004).

Wayson, R. L. Relationship Between Pavement Surface Texture and Highway Traffic Noise. NCHRP Synthesis 268. Transportation Research Board, National Research Council, Washington, D.C., 1998.

Arizona Specification for

Asphaltic Concrete Friction Course

(414ACFAR, 6/18/04)

SECTION 414 - ASPHALTIC CONCRETE FRICTION COURSE (ASPHALT-RUBBER):

414-3 Materials: of the Standard Specifications is modified to add:

For comparative purposes, quantities shown in the bidding schedule have been calculated based on the following data:

Spread Rate, lb/yd ²	XXXXX
Bituminous Material, %	XXX.X
Mineral Admixture, %	1.0

The spread rate specified includes **XXX** percent for leveling to provide a minimum **XXXXX**-inch thickness above the leveling thickness. The exact spread rate will be determined by the Engineer.

414-3.02 Mineral Aggregate: Table 414-1 of the Standard Specifications is revised to read:

TABLE 414-1 MIX DESIGN GRADING LIMITS FOR MINERAL AGGREGATE (Without Admixture)	
Sieve Size	Percent Passing
3/8 Inch	100
No. 4	30 - 45
No. 8	4 - 8
No. 200	0 - 2.5

414-3.02 Mineral Aggregate: the "Sand Equivalent" data line in Table 414-2 of the Standard Specifications is revised to read:

TABLE 414-2 MINERAL AGGREGATE CHARACTERISTICS		
Characteristic	Test Method	Requirement
Sand Equivalent	Arizona Test Method 242	Minimum 45

414-3.04 Bituminous Material: the first paragraph of the Standard Specifications is revised to read:

Bituminous material shall be asphalt-rubber conforming to the requirements of Section 1009 of these specifications. The asphalt-rubber shall be Type **XXXXX**. The crumb rubber gradation shall be Type B conforming to the requirements of Section 1009.

414-7.06(A)(1) Dates and Surface Temperature: the first paragraph of the Standard Specifications is revised to read:

Asphaltic concrete shall be placed between the dates of **XXXXX** and **XXXXX** and only when the temperature of the surface on which the asphaltic concrete is to be placed is at least 85oF.

414-7.09 Surface Requirements and Tolerances: the title and text of the Standard Specifications are revised to read:

414-7.09 Smoothness:

Asphaltic concrete shall be compacted as required, smooth and reasonably true to the required lines, grades, and dimensions.

If the Special Provisions do not require the smoothness to be determined in accordance with Subsection 109.13, the final asphaltic concrete surface will be tested by the Engineer utilizing a 10-foot straightedge. The finished surface shall not vary more than 1/8 inch from the lower edge of the straightedge when it is placed in the longitudinal direction, or 1/4 inch when placed in the transverse direction across longitudinal joints. All deviations exceeding the specified tolerance shall be corrected by the contractor.

If the Special Provisions require smoothness to be determined in accordance with Subsection 109.13, the Engineer may also test the smoothness utilizing a 10-foot straightedge as specified above.

414-9 Basis of Payment: of the Standard Specifications is modified to add:

When required in the Special Provisions, payment for smoothness shall be made in accordance with the requirements of Subsection 109.13.

Table 8 illustrates a brief summary of precipitation rates for three cities in Washington and three cities in Arizona.

Table 8. Average Precipitation Rates for Cities in Washington and Arizona

Month	Washington			Arizona		
	Olympia	Seattle	Spokane	Flagstaff	Phoenix	Tempe
January	7.54	5.13	1.82	2.18	0.83	1.01
February	6.17	4.18	1.51	2.56	0.77	1.04
March	5.29	3.75	1.53	2.62	1.07	1.15
April	3.58	2.59	1.28	1.29	0.25	0.25
May	2.27	1.78	1.60	0.80	0.16	0.21
June	1.78	1.49	1.18	0.43	0.09	0.07
July	0.82	0.79	0.76	2.40	0.99	0.89
August	1.10	1.02	0.68	2.89	0.94	1.20
September	2.03	1.63	0.76	2.12	0.75	0.86
October	4.19	3.19	1.06	1.93	0.79	0.85
November	8.13	5.90	2.24	1.86	0.73	0.80
December	7.89	5.62	2.25	1.83	0.92	1.03
Totals	50.79	37.07	16.67	22.91	8.29	9.36

In addition, Figure 7, Figure 8, and Figure 9 graphically illustrate the temperature and precipitation measurements for the Seattle, Phoenix, and Flagstaff areas.

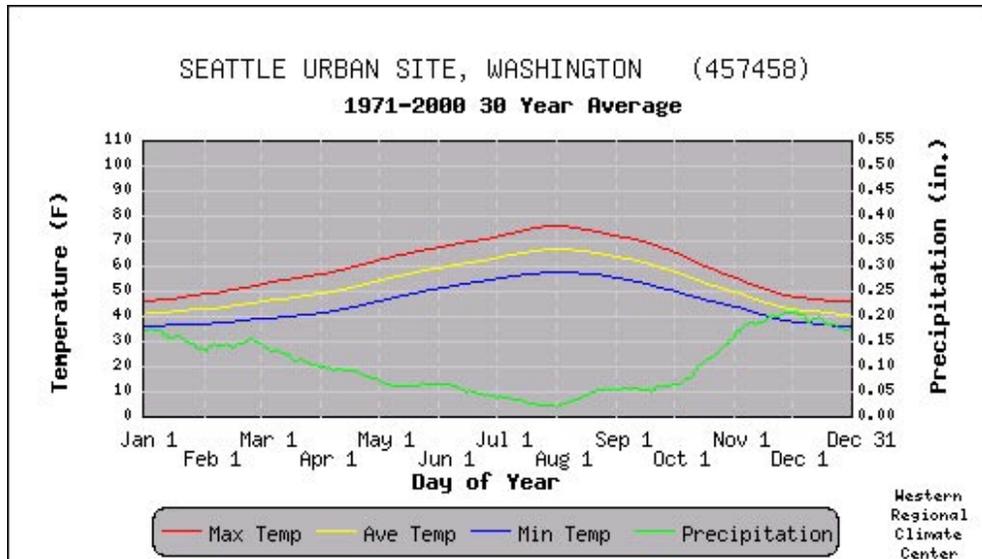


Figure 7. Temperature and Precipitation Information for Seattle

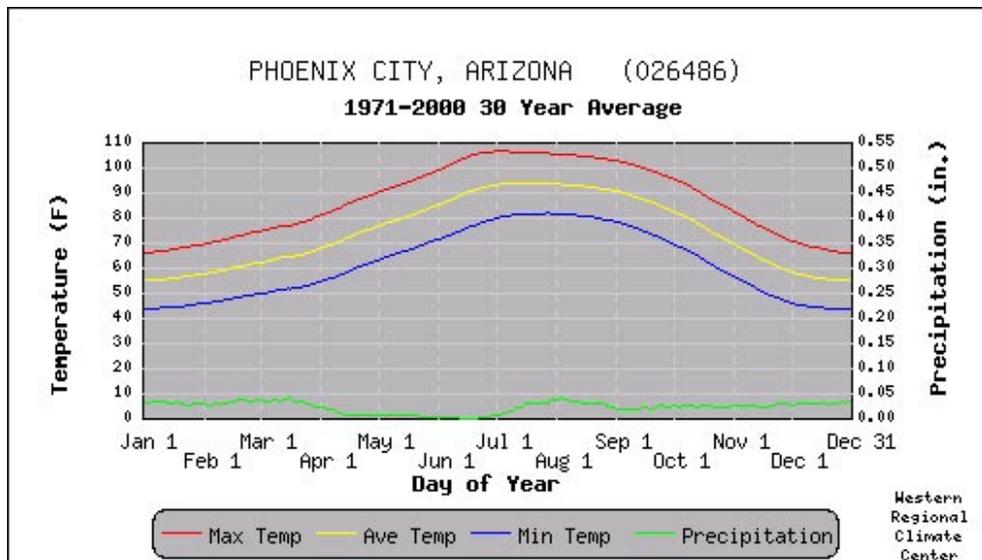


Figure 8. Temperature and Precipitation Information for Phoenix

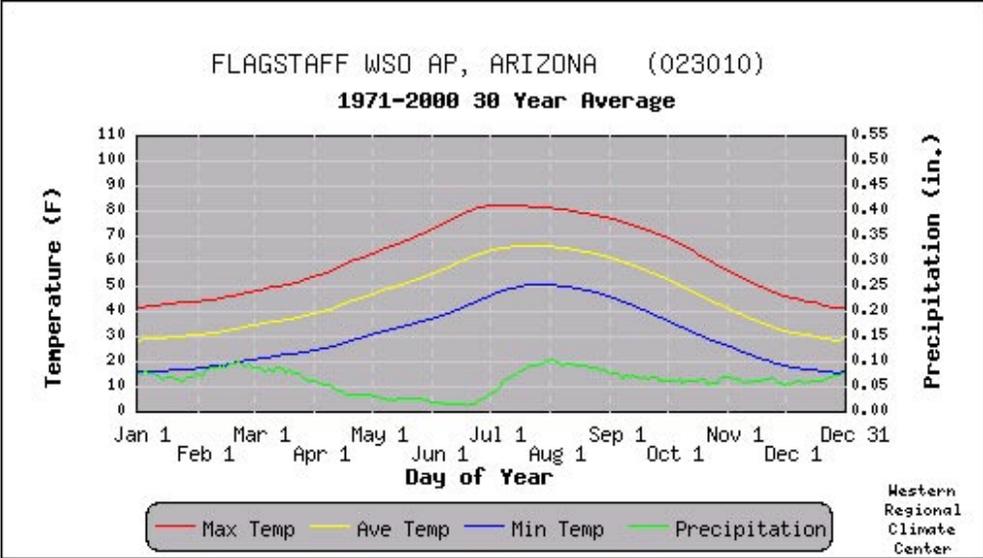
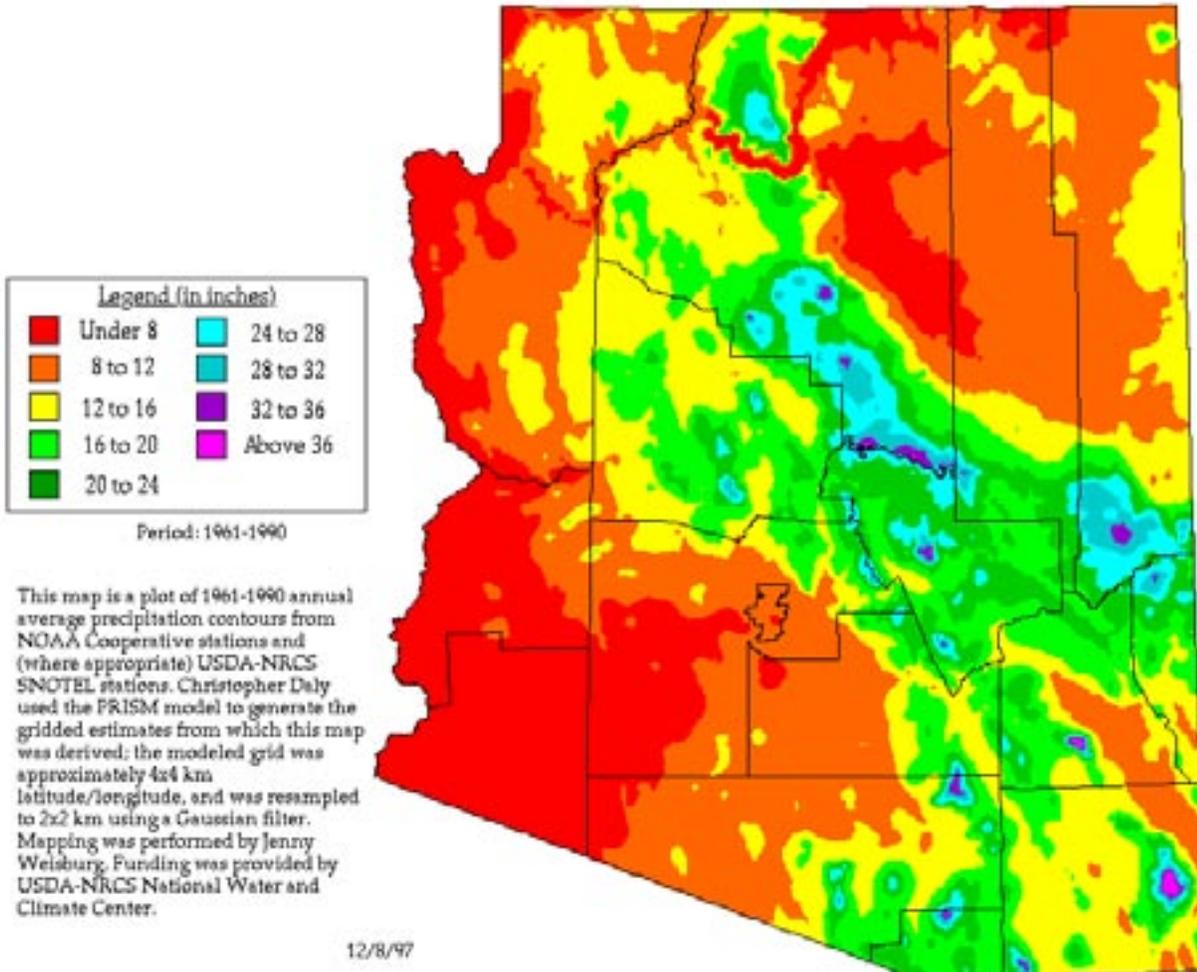


Figure 9. Temperature and Precipitation Information for Flagstaff

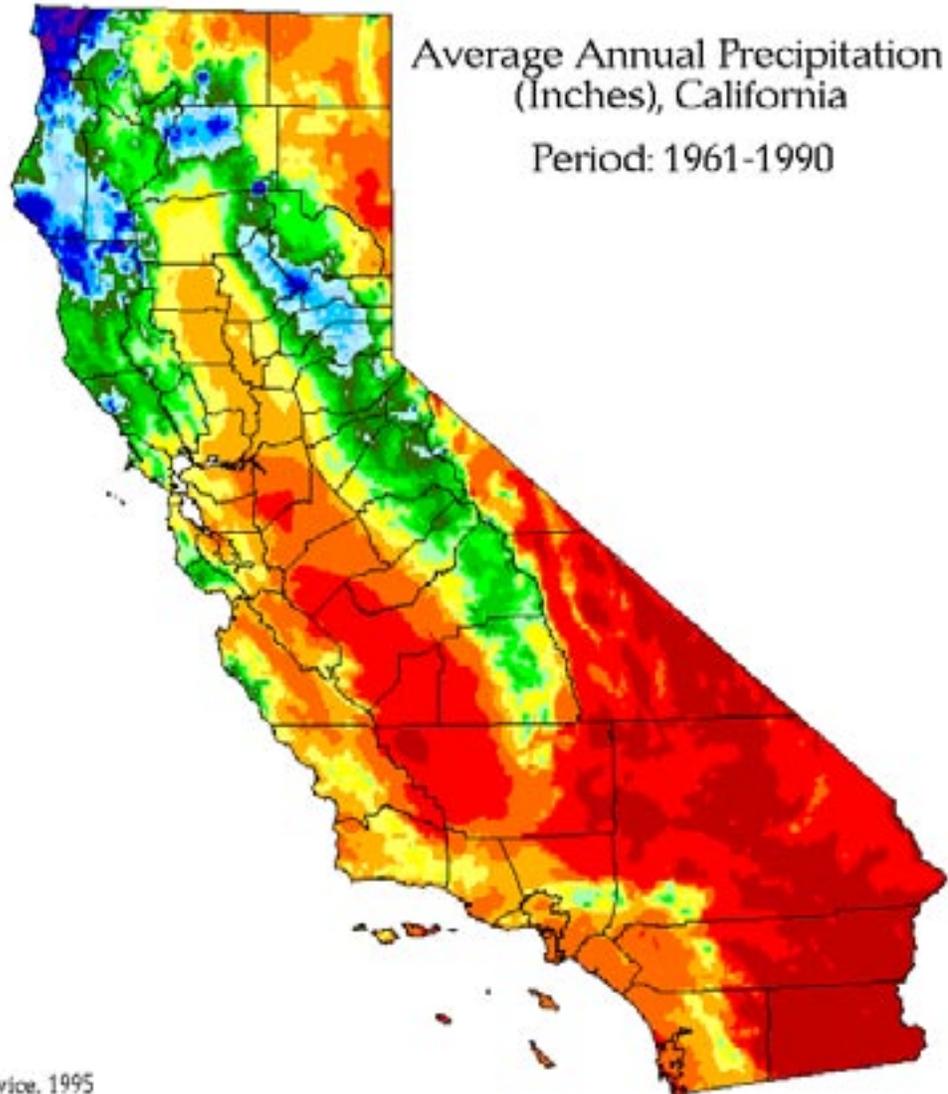
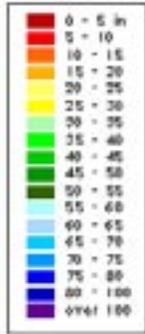
Table 8 and the above three figures clearly illustrate that there are dramatic differences between the climates of Washington and Arizona.

The information contained in this appendix was obtained from the Western Regional Climatic Center website at <http://www.wrcc.dri.edu/CLIMATEDATA.html>.

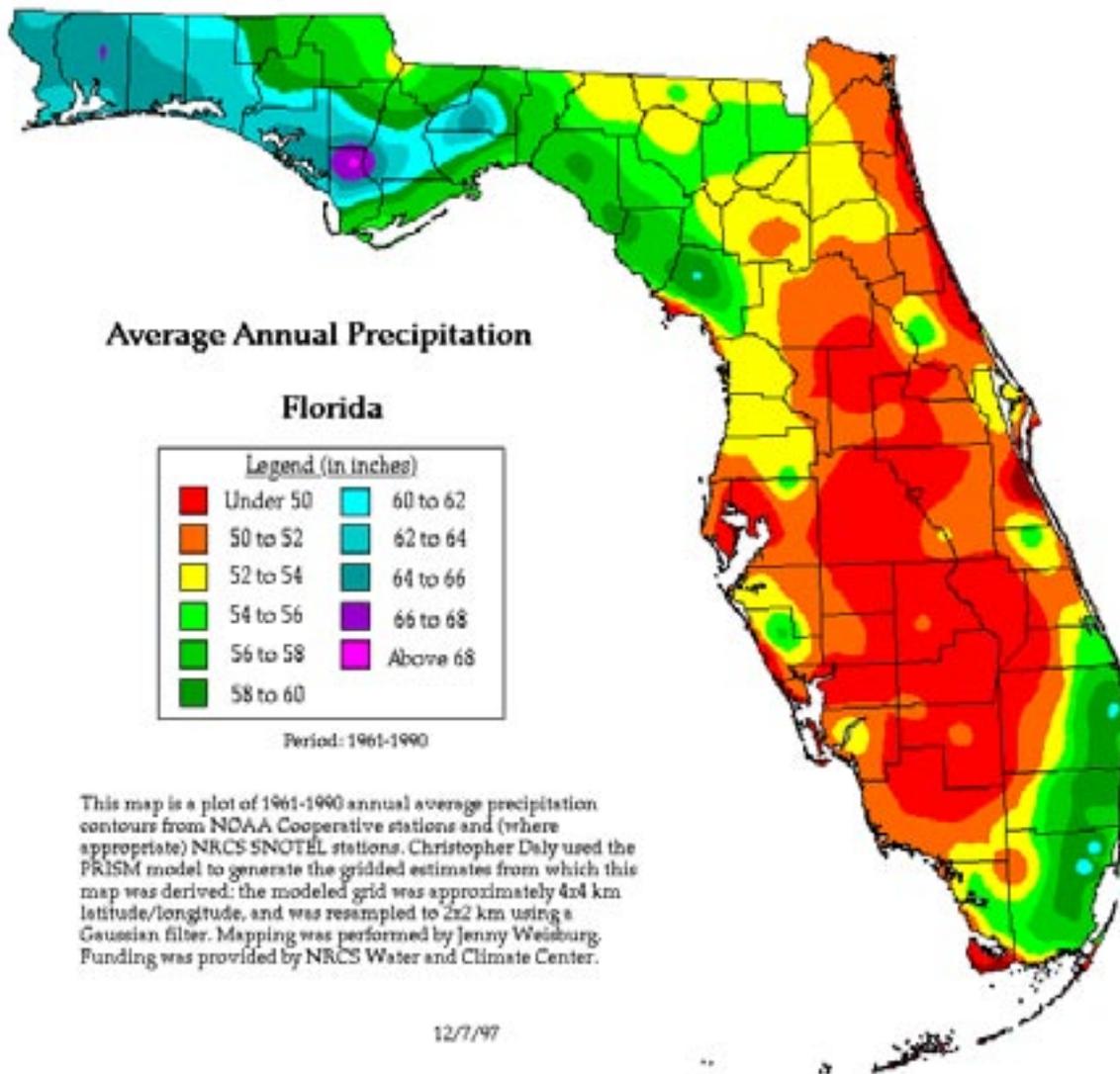
Average Annual Precipitation Arizona



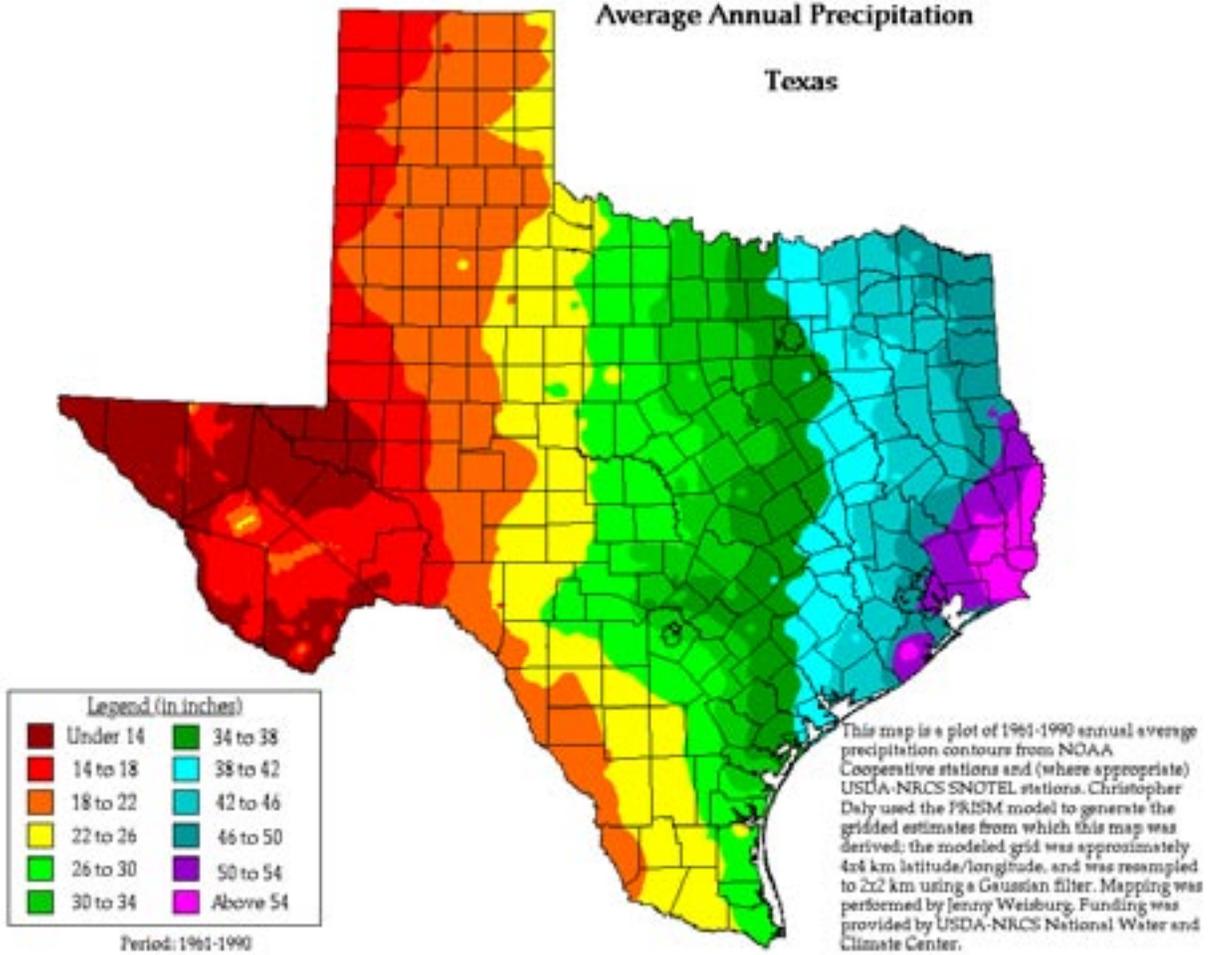
Average Annual Precipitation
(Inches), California
Period: 1961-1990



Oregon Climate Service, 1995



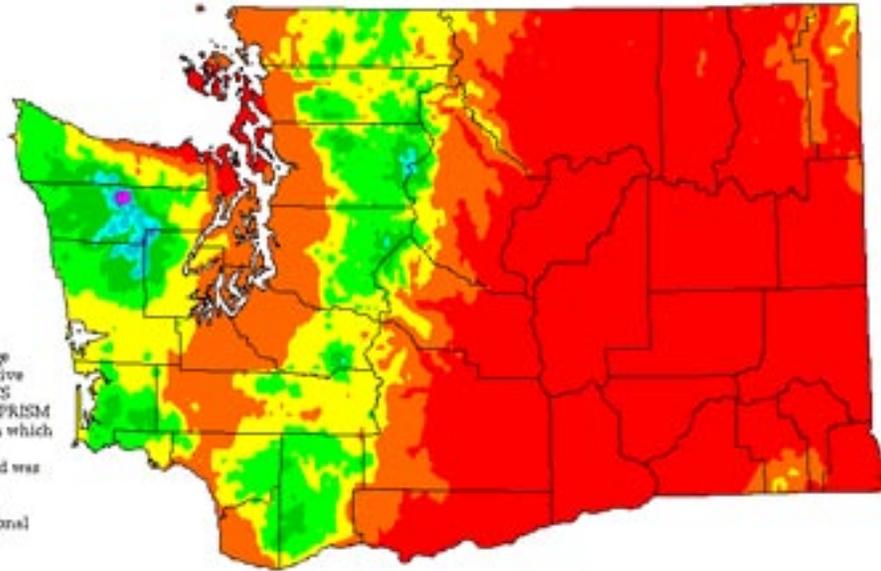
Average Annual Precipitation Texas



Average Annual Precipitation Washington



Period: 1961-1990



This map is a plot of 1961-1990 annual average precipitation contours from NOAA Cooperative stations and (where appropriate) USDA-NRCS SNOTEL stations. Christopher Daly used the PRISM model to generate the gridded estimates from which this map was derived; the modeled grid was approximately 4x4 km latitude/longitude, and was resampled to 2x2 km using a Gaussian filter. Mapping was performed by Jenny Weisburg. Funding was provided by USDA-NRCS National Water and Climate Center.

12/7/97

- Considers a typical 8-lane urban highway.
- Work zone hours are 10 p.m. to 5 a.m.
- Assumed a growth rate of 1.5 percent and 6.5 percent trucks.
- Considers 1-mile section of roadway in both directions (i.e., 8 lane miles).
- Traffic: 180,000 ADT (total for both directions) (In 2003, I-5 @ Fife ADT ~ 180,000, maximum I-5 ADT ~ 278,000 @ MP 163.54).
- ADT capped at 300,000 for 8-lane.
- Does not consider capacity improvements that might take place.
- Two lanes in each direction closed during work zone hours.
- Overlay cost of \$140,000 per lane mile is assumed for both OGFC and HMA.
 - OGFC material cost has been about 20 to 25 percent higher than HMA but tonnage is lower per lane mile.
 - Total costs are expected to be and are assumed to be similar in the absence of project specific data.
- Represents cost in 2004 dollars.

A joint Nordic research project was commissioned to study the noise reduction of different types of HMA surfaces (Raaberg et al., 2001). The method to measure noise was similar to the Statistical Pass-By Method (ISO 11819-1) and was performed on three sections of porous asphalt, one section of OGFC, and one section of dense-graded HMA. In terms of noise, the small grain porous asphalt performs better than larger grain porous asphalt, OGFC, and dense-graded HMA. Porous asphalt is less noisy than dense-graded for the first six years (approximately 3 to 4 dBA for 8 millimeter aggregate size surfacing and less for 11 millimeter aggregate size surfacing) and the OGFC was noisier than the dense-graded HMA. After about seven years, the noise reduction disappears and raveling starts to become a problem. If no cleaning is performed, the permeability is drastically reduced after two years, but the noise reduction is still effective. Lastly, a change in the texture properties doesn't influence the friction properties.

In NCHRP 284 (Huber, 2000), it was reported that the typical noise reduction at highway speeds is about 3 dBA, which results in a 50 percent decrease in noise pressure. It was also found that at high speeds, there is a loss in permeability but the noise reduction still effective. At low speeds, there is a loss in permeability and noise. These results are from numerous studies that were summarized within NCHRP 284 and it does not mention how the noise was measured or what the age of the pavements were when they were measured.

Within Transportation Research Record 1265 (1990), there were 11 papers that discussed numerous aspects of porous pavements internationally.

Highlights from these papers include:

- In France, the porous asphalt is typically 1.5 to 2 inches thick and has a noise reduction of anywhere from 3 to 6 dBA over dense-graded HMA. When thin porous asphalt is used (i.e., 1.5 inches or less), the noise reduction is on the order of 2 to 3 dBA over dense-graded and when thick porous asphalt is used (i.e., 2 inches), the noise reduction increases to 5 to 6 dBA. These noise reductions were measured via the coast-by method (ISO R 362), which is with the engine off. Also in France, another type of noise measurement was performed. This experiment incorporated the use of two vehicles with three types of tires and the noise was estimated by linear regression on the maximum sound pressure levels. Through this experiment, it was found that when new pavements (porous asphalt and dense-graded HMA) were tested within six months of construction and after one year in place, there was a difference of 2 dBA and 1 dBA between the porous and dense-graded pavements, respectively.

- An experiment conducted in Italy using a version of roadside testing (3.5 and 7.5 meters from the traffic lane and free field acoustic conditions) on new pavements found that there was a difference of 3.5 to 4.7 dBA between porous and dense-graded pavements. This testing was performed with one passenger vehicle and one truck at constant speed, with a white noise generator atop of the vehicle that exceeded the vehicle noise by at least 10 dB, and both in gear and with the engine turned off.
- Another experiment, this one in the UK, on new pavement measured the peak noise levels and speeds from 7.5 meters off the centerline and used a regression of the speed versus noise to determine the noise level at 90 km/hr. What the researchers found was that the peak noise levels were about 4 to 5.5 dBA lower for the pervious pavements (over the conventional nonporous pavements) when testing a new, untrafficked roadway. They tested the same roadway sections over time (a period of 48 months) and found that the peak noise levels remained relatively constant over this time period (about 4 dBA).
- Belgium research has shown that, when using a standard vehicle with the engine off at 80 km/hr and measuring at the roadside 7.5 meters from the vehicle and 1.2 meters off the pavements, there is a 6 to 10 dBA difference between porous pavement and transversely grooved PCC and a 2 to 3 dBA difference over conventional or chipped asphalt.
- In Switzerland, work was performed with a one-wheeled trailer to determine the rolling tire noise on new pavements. There were two microphones near the wheel — one behind the tire and one to the side of the tire. The researchers found that there is a definite difference in the noise increases with increasing speed between porous and dense-graded HMA. For instance, at 50 km/hr, a 1.5 dBA difference was determined, while at 60 and 80 km/hr, the difference increased to 3.5 and 5.0 dBA, respectively. They also found that the binder film thickness on the surface of the roadway seems to have a noise reduction effect. Another study in Switzerland was performed with a roadside microphone 6 meters from the roadside edge and 1.7 meters high. The vehicles were kept at a constant speed and the difference between a porous asphalt and a dense-graded HMA was anywhere from 1 to 5 dBA and 3 to 7 dBA when compared to old PCC.
- In Spain at a test track, the rolling tire noise was determined on porous asphalt, dense-graded HMA, and a slurry seal. It was found that there was a reduction of 3 to 5 dBA from the dense-graded or slurry seal to the porous asphalt.
- Another experiment was performed with a passenger car traveling at 80 km/hr in dry conditions and was found to produce a 3 dBA difference between the porous and dense-graded HMA.

According to Glazier et al. (1991), a study was performed to determine the noise of several different pavement types. The noise was determined in accordance with the provisions of Australian Standard 2702 under still, dry conditions. The microphone was generally 4 to 7 meters from the center of the nearest traveled lane. With this method, it was found that the loudest surface is dense-graded PCC and the quietest surface is OGFC, which produced a 3 to 6 dBA decrease over dragged and grooved PCC surfaces, respectively. The average drop in noise was 4.5 dBA from OGFC over PCC.

Sandberg (2001) tested different road surfaces according to ISO 11819-2, which is the Close-Proximity Index (CPX). He found that these different road surfaces give a large variation in noise levels. For instance, porous asphalt with 2 to 6 millimeter top course and 11 to 16 millimeter bottom course was the quietest at 90 dB and the loudest was PCC transversely brushed at 100.2 dB.

The FHWA performed a comparative noise level study (Kandahl, 2002) where the noise was measured 50 feet from the roadway when a station wagon with radial recap tires was operated at 65 mph. There were four new pavements tested and the averages for each section are: OGFC 67 dBA, dense-graded HMA 69 dBA, PCC 70 dBA, and chip seal 72 dBA. Also, the Transportation Research Laboratory in the UK demonstrated that noise level reductions were maintained over a long period of time (approximately four years). OGFC was able to maintain a 4 dBA noise reduction over dense-graded HMA in the dry condition, OGFC was able to maintain an 8 dBA noise reduction over dense-graded HMA in the wet condition, and OGFC was able to maintain a 10 to 11 dBA noise reduction over broomed PCC.

According to Herman et al. (2000), PCC was the loudest pavement tested with a difference of 6.7 dB between the open-graded and the random transverse grooved PCC when tested according to ISO 11819-1 (the Statistical Pass-By Method). The sites tested included open-graded, dense-graded, SMA, and PCC (transverse, random transverse, and longitudinally grooved). The test temperature and traffic speed were held between 5 to 30°C and between 55 to 65 mph, respectively. Most of the pavements tested were one-year-old, but a few were up to seven years old. The HMA pavement that generated the highest noise was the three-year-old SMA and the PCC pavement that generated the lowest noise was the longitudinally grooved PCC. The results of the SPB noise levels are as follows:

- OGFC about 82 dBA
- Dense-graded around 85 – 86 dBA
- Stone Matrix Asphalt around 86 dBA
- PCC around 87 – 89 dBA

Testing was performed in Colorado with the NCAT Close-Proximity Method (CPX) trailer on 18 pavement surfaces (Hanson et al). These pavement surfaces include OGFC, SMA, HMA, NovaChip, and PCC and vary in age from less than a year old to 11 years. Testing with the CPX trailer was done at 60 mph using two different tires on each pavement surface. The research discovered that noise and frequency matter. Different surfaces have different peak noise levels. Higher frequency noise can attenuate farther away from the source than can low frequency noise. OGFC peaks around 600 Hz, while the other four surface types typically peak around 1000 Hz. The OGFC has a noise level of 95.3 dBA, while the other surfaces range from 95.1 to 101.4 dBA. Besides the OGFC, the lowest noise levels were the 9.5 millimeter SMA and NovaChip surfaces at 95.1 dBA. Most of the highest noise levels were PCC: longitudinally tined was 97.5 to 98.6 dBA, carpet or Minnesota drag was 97.9 dBA, ground PCC was 98.0 dBA, and transversely tined was 102.6 dBA (11 years old). The results from the NCAT study were also reported here and the average noise levels (dBA) for different surfaces were:

- 93 OGFC
- 95 Dense-graded HMA
- 96 Stone Matrix Asphalt
- 97 OGFC (coarse)
- 98.1 PCC diamond ground
- 98.8 PCC longitudinal tines
- 101.6 PCC longitudinal grooves
- 102.6 PCC transverse tines

According to Kandahl (2003), multiple tests using various test methods were conducted in Europe and it was found that the average noise reduction for OGFC is 3 to 5 dBA quieter than HMA and 6 to 7 dBA quieter than PCC.

A study was performed with hot rolled asphalt (HRA) and two different aggregate sizes of exposed aggregate concrete surfaces (EACS) (Chandler et al., 2003). The aggregate sizes in the EACS utilized were 6 to 10 millimeters and 8 to 14 millimeters. The Close Proximity Method was used to measure the noise levels. After 12 months of opening the sections, the average noise levels for the HRA sections with light traffic traveling at 110 km/h and heavy traffic traveling at 90 km/h were 84.1 and 88.9 dBA, respectively. For the 6 to 10 millimeter EACS, they were 82.7 and 87.7 dBA, respectively. For the 8 to 14 millimeter EACS, the noise levels were 84.3 and 89.2 dBA, respectively. All the noise levels are similar under similar conditions (less than 2 dBA difference). These surfaces were tested again at 63 months after

construction and the EACS surface was louder after this period of time with a larger difference at the higher frequencies (for light vehicles). After the 63 months, the HRA was approximately the same at the higher frequencies with light vehicles, but louder at the lower frequencies. Lastly, the researchers determined that the skid resistance of the EACS depends mainly on the microtexture of the aggregate and the texture depth needs to be consistent for increased skid resistance.

The NCHRP Synthesis 268 (Wayson, 1998) reported that pass-by noise levels increase for porous surfaces over time as wear occurs. Still, the porous or OGFC are quieter than PCC (Hessian-dragged or longitudinal smoother, textured with just longitudinal sweep), which is about 2 to 2.5 dBA quieter than HMA. For the porous surfaces, there was an increase of three dBA over a seven-year period, but they still remain quieter than PCC.

In the Netherlands (Heerkens, 1989), open-graded rubberized asphalt was tested for noise levels in urban areas. The pavement consisted of 4 to 8 millimeter crushed stone, filler (limestone, fly ash, or hydrated lime), and rubberized bitumen. Rolling noise measurements were taken on new pavements (different sizes of crushed stone with filler and bitumen) and it was found that the open-graded rubberized bitumen reduces traffic noise by 2.5 dBA for continuous traffic flow with ten percent trucks and an average speed of 50 km/h. If just passenger cars are considered, the reduction in noise level is 3.2 dBA. Also, it was found that the open-graded rubberized asphalt reduces noise at many frequencies, between 500 to over 4,000 Hertz.

