Environmentally Friendly Elimination of Moss from Open-Graded Asphalt Pavement

Requested by
Deborah Harmon, Caltrans District 1

April 14, 2011

The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

Caltrans has discovered moss growing on U.S. Highway 101 in Del Norte and Humboldt counties, U.S. Highway 199 near the Smith River and other roadways in Caltrans District 1. These areas are heavily forested, and the heavy tree canopies shielding roadways reduce sunlight and contribute to moisture retention on the pavement. In the interest of providing a drier—and safer—pavement, Caltrans has used an open-graded asphalt pavement mix with a maximum aggregate size of 1 inch on some roadways in District 1. Open-graded mixes consist mostly of aggregate particles with few fines. They provide a more porous surface that quickly drains surface water to reduce hydroplaning.

Moss growth is noted mostly in shoulders to the right of the motorist and in medians. In a few areas, moss has made its way into the edge of the traveled portion of the roadway, just reaching the white stripe painted 2 inches in from the edge of the traveled way. The roadway segments with moss growth adjacent to the traveled way have passed skid tests, which indicate an acceptable coefficient of friction (the frictional force between tires and the roadway). It is unclear if the moss growth is impacting safety.

Caltrans is interested in exploring options that could contribute to safety improvements to these roadways in District 1 and for roads in other areas of the state with similar conditions. Among the possibilities are the removal of moss and the prevention of its regrowth to improve friction. Because affected roadways exist in close proximity to sensitive environmental resources, any means used to address moss growth must pose minimal hazards to the environment.

This Preliminary Investigation seeks to capture the best practices established by state, national and international agencies in moist, coastal areas to address the cost-effective, environmentally friendly elimination of moss on open-graded asphalt pavement. In addition to examining published research and gathering expert recommendations, we also explore environmentally friendly treatments to manage roadside vegetation.

Summary of Findings

This Preliminary Investigation includes a Survey of Current Practice in managing moss growth and an examination of Alternative Methods for Roadside Vegetation Control.The two sections of this Preliminary Investigation are summarized below.

Survey of Current Practice

A review of the transportation literature yielded no published research describing how transportation agencies treat or inhibit moss growth on open-graded pavement—either domestically or internationally.

In the absence of published research, we sought anecdotal information from state and national agencies in areas with warm, moist climatic conditions conducive to moss growth on pavement. We contacted representatives from California state parks and national parks, and four states—Florida, Louisiana, Oregon and Washington. We also discussed possible treatment options with Caltrans District 1 staff.

While some of our contacts offered possible treatment options, we received only one report of moss growth on open-graded asphalt pavement outside of California—at Olympic National Park in Washington. The park treats moss with a rough broom and snowplowing operations. Moss on pavement is an issue for Oregon DOT, but the pavement in question is chip seal, not an open-graded mix. (Chip seal is an application of a bituminous binder followed by an aggregate that is then rolled to embed it into the binder.) In Washington, dense-graded pavement mixes are preferred for their performance. Open-graded asphalt is not used in park units within California State Parks' North Coast Redwoods District. These parks are located in Caltrans District 1.

The table below summarizes treatment options suggested or considered by those we contacted.

Treatment	Description
Pavement mix selection	Avoid the use of open-graded mixes in areas that do not get a lot of traffic.
	Avoid the use of open-graded friction courses in warm, moist climates. Cracks and other fissures can fill with wind-borne fines and hold moisture, creating an environment conducive to the growth of mold—and perhaps moss.
Synthetic alternatives	*Wet & Forget*. This commercial product can be used in residential and commercial applications. Marketed as noncaustic, nonacidic and safe for all outdoor surfaces, the product's active ingredient is alkyl dimethyl benzyl ammonium chloride.
	Glyphosate. Two applications per year of this herbicide should be adequate to kill the moss. Glyphosate is the active ingredient in commercial herbicides such as Roundup.
Natural-based products	*Baking soda, vinegar, biodegradable fatty acids.* Certain kinds of soap and borax are also recommended.
	Electrolyzed water. Identified as a cost-effective and environmentally friendly alternative that can be used as a contact fungicide on plant surfaces and for general sanitation in greenhouses. A cell electrolyzes water, resulting in two types of water possessing different properties: • An electrolyzed basic solution that has strong reducing potential and can be used as a cleaning solution. • An electrolyzed acid solution with a strong oxidation potential that can be used as an alternative to chlorine-based compounds for killing bacteria.

Treatment	Description
Mechanical methods	*High-pressure, low-volume power washer*. A small-scale test of this mechanical method involves the use of a portable power washer to determine how much pressure is needed to remove moss when moving along at a reasonable rate of speed (that is, 10 mph). *Moss cutting machine.* This machine, used by an irrigation district in Oregon to remove moss from canals, applies similar technology.
	Shielded high-intensity ultraviolet light. This light source might burn off moss or delay its growth by triggering a negative phototrophic response. This method is used to treat recirculating water in greenhouses to remove algae and fungi.
	Infrared heater. An infrared heater is used to direct a propane flame at a ceramic or metal plate, which radiates heat onto the moss. Other applications use water and intense heat in an enclosed space.
Road striping/paint	*White fog lines*. If moss is not present on the white fog lines painted along the edge of the traveled way, or is growing more slowly than in other areas, perhaps the paint has a retarding effect. Portions of the less-traveled areas might be painted white to inhibit moss growth and provide for better traction.
	Augmenting road striping paint with elemental zinc. As zinc leaches out of road striping paint, it might hinder the growth of moss on the highway in a manner similar to how galvanized metal that leaches zinc controls moss on a roof.

Alternative Methods for Roadside Vegetation Control
Given the lack of recommendations in the literature for the environmentally friendly removal of moss on open-graded asphalt pavement, we looked for practices used to control roadside vegetation that might have some applicability for the moss growth identified in District 1. Reports from five state DOTs—California, Massachusetts, New York, Oregon and Washington—provide information about natural-based alternatives and mechanical methods used to control roadside vegetation.

In general, researchers found that alternatives to standard synthetic herbicides such as those containing glyphosate are not as effective and tend to be more costly. The additional cost is related to higher material costs and the repeated applications required to achieve acceptable levels of control.

The alternative products and methods evaluated by researchers include:

- Mechanical treatments, including heat applications from infrared technology, ultraviolet light, steam and flame.
- Natural-based products that contain acids (vinegar, fatty (or pelargonic), citric and acetic acids).
- Natural-based products that contain plant oils (clove) or corn gluten meal.

A common theme in these reports is the recommendation for further research.

Gaps in Findings

Our research did not uncover published research—domestic or international—that addresses the removal of moss from open-graded asphalt pavement. Almost all of the state and national agencies we contacted report little or no use of open-graded pavements. When we did encounter an agency reporting both moss

growth and the use of open-graded pavement—Olympic National Park—we did not learn of a focused moss removal effort beyond brooming and snow removal.

It is not clear from our investigation whether other agencies have found that pavement types or mixes other than open-graded asphalt pavement are a better choice to prevent moss growth in areas with the climatic conditions, heavy tree canopy and sensitive resources found in District 1.

Naturally occurring compounds that might be used as an alternative to synthetic herbicides tend to be less effective and more costly than their synthetic counterparts. Researchers appear to agree that further study is required.

Next Steps

Caltrans might consider the following in its continuing evaluation of moss growth on open-graded asphalt pavement:

- Follow up with state agencies and state and national parks that have elected to forgo the use of open-graded asphalt to identify the types of pavements used and pavement performance.
- Follow up with Oregon DOT to determine if further work is expected in that agency's examination of moss growth on pavements scheduled for chip sealing.
- Identify other pavement treatments, such as roughing up the pavement, that create a coefficient of friction similar to that provided by open-graded asphalt and serve the same purpose of wicking water away from the surface of the pavement.
- Consider trials of alternative treatment methods. Such treatments might include:
    - **Synthetic alternatives.** Commercial products such as those that contain glyphosate or other products such as Wet & Forget may be effective but not meet the environmentally friendly standard.
    - **Natural-based products.** Products that contain citric, acetic or pelargonic acid; clove oil; and corn gluten meal have been included in trials conducted by other agencies. Results, where available, indicate that these products are generally less effective than synthetic alternatives and tend to be more costly to apply.
    - **Electrolyzed water.** This relatively new process uses water and a saturated sodium chloride solution to create an electrolyzed acid solution that can be used as a contact fungicide on plant surfaces.
    - **Mechanical methods.** Brooming is used in Olympic National Park to remove moss from open-graded pavement. Oregon DOT has investigated the use of infrared heaters; District 1 staff has also mentioned the use of infrared heaters as a possible treatment method. Other possibilities include shielded high-intensity ultraviolet light and the use of paint—the white paint used for fog lines or road striping paint augmented with elemental zinc—to inhibit moss growth.

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the following individuals:

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Survey of Current Practice

A review of the transportation literature yielded no published research describing how transportation agencies treat or inhibit moss growth on pavement—either domestically or internationally. In the absence of published research, we sought anecdotal information from state and national agencies in areas with the warm, moist climatic conditions conducive to moss growth on pavement. Our contacts are associated with **California State Parks**; **National Parks**; and **State Agencies** in Florida, Louisiana, Oregon and Washington in addition to Caltrans. In a few cases, our contacts shared information about treatments developed or recommended by other agencies.

California State Parks

North Coast Redwoods District

Open-graded asphalt is not used in park units. Light moss growth has been noted along the Newton B. Drury Parkway, but the parkway is not paved with open-graded asphalt.

Contact: Brian R. Merrill, Senior Engineering Geologist, North Coast Redwoods District, California State Parks,
(707) 445-5344, bmerr@parks.ca.gov.

National Parks

We began by contacting the Transportation Program Managers for the Pacific West and Southeast regions of the National Park Service. These contacts asked colleagues in various park units throughout their respective regions to offer their experiences.

Pacific West Region

The Pacific West Region's Transportation Program Manager is unaware of problems with moss growth on open-graded asphalt pavements. He notes that moss growth may be ignored because the National Park Service tends to err on the side of protecting sensitive resources. There is no action taken to address moss removal in the absence of engineering reports indicating that the moss growth is causing a problem.

Contact: Justin DeSantis, Transportation Program Manager, Pacific West Region, National Park Service, (510) 817-1385, justin_desantis@nps.gov.

Olympic National Park

Moss is present on roadways in Olympic National Park, which includes a fair amount of open-graded asphalt and chip seal. Our contact notes that "moss grows on everything, open graded or not. I had moss growing on the roof of my car." Generally, the park does not use chemical treatments given concerns about chemical release into watersheds. Our contact reports the following treatments in use in the park:

Treatment	Description
Broom	A rough broom is used to treat moss during the summer season.
Snowplow	Snowplows help keep moss under control in areas where plowing is needed.

Contact: Carl Elleard, Civil Engineer, Olympic National Park, (360) 912-1625, carl_elleard@nps.gov.

Yosemite National Park

Moss growth is not known to be a problem on vehicular pavements in Yosemite National Park. While moss growth is reported on trails, it has not been a significant issue. Moss does not last very long where it does appear, with extended dry conditions in the park causing the moss to die back in late spring when the trails are in full use.

While not presenting a problem in Yosemite, our contact suggests certain types of soap, vinegar or borax as treatments to remove moss, in addition to the following commercial product:

Treatment	Description
Wet & Forget	This commercial product can be used in residential and commercial applications. Marketed as noncaustic, nonacidic and safe for all outdoor surfaces, the product's active ingredient is alkyl dimethyl benzyl ammonium chloride. Our contact notes that it can take a month or more to see results, depending on weather conditions. Once the moss dies, reapplication may not be required until the following year. See Related Resources below for more information.

Related Resources:

Wet & Forget
http://www.wetandforget.com/index.php
New to the United States, Wet & Forget has been used residentially and commercially for more than 30 years in New Zealand and Australia. Large areas can be covered quickly using an agricultural sprayer with a diaphragm pump system; applying to a dry surface provides the best penetration. Total saturation of the surface with Wet & Forget is essential to obtain good results with moss, mold, mildew or algae stains. A material safety data sheet is available by contacting sales@wetandforget.com.

Reregistration Eligibility Decision for Alkyl Dimethyl Benzyl Ammonium Chloride (ADBAC), U.S. Environmental Protection Agency, EPA739-R-06-009, August 2006.
http://www.epa.gov/oppsrrd1/REDs/adbac_red.pdf
This document provides the Environmental Protection Agency's alkyl dimethyl benzyl ammonium chloride (ADBAC) risk assessment and the agency's conclusions on the dietary, drinking water, occupational and ecological risks posed by exposure to ADBAC.

Contact: Michael Pieper, Civil Engineer, Yosemite National Park, (209) 379-1263, michael_pieper@nps.gov.

Talent Irrigation District

A Yosemite National Park contact provided information about moss removal efforts by an Oregon irrigation district.

The Warm Springs Irrigation District in Vale, OR, developed a moss cutting machine in response to a ban on the use of chemicals for moss control. The Talent Irrigation District in Talent, OR, made minor modifications to this machine and reports on its use during 2004 and 2005 to remove moss from the canal system in the Rogue River Basin.

The moss cutter uses a high-pressure water system with nozzles to cut moss loose from the canal prism to maintain the canal's design capacity and allow for irrigation water deliveries. A modification of this treatment method might be suitable for use on pavement.

We contacted the Talent Irrigation District to learn about more recent use of the moss cutter. The district's manager reports that the moss cutter was retired three years ago. While the moss cutter worked, it was slow and expensive to operate and maintain. The district now uses moss rakes attached to excavators to remove algae and pondweed from the canal. The new system has its problems, but the district has refined the process to fit its needs. The district's manager notes that while the moss cutter might be effective in a pavement application, he questions whether the process can be deemed environmentally friendly given the large amount of water needed to operate the system at a very high pressure.

Treatment	Description
Moss cutting machine	Developed for use on waterways, this machine uses a high-pressure water system with nozzles to cut moss loose and prepare it for pickup. See Related Resources below for more information.

Related Resources:

"Moss Control with New Moss Cutter Machine," newsletter, Talent Irrigation District, Fall 2004.
http://www.talentid.org/mn.asp?pg=News_Fall_04
Scroll halfway down the page to find the article that discusses development and early use of the moss cutting machine.

"Moss Control with Moss Cutter Machine," Newsletter, Talent Irrigation District, Spring 2005.
http://www.talentid.org/mn.asp?pg=News_Spring_05
Scroll halfway down the page to find the article that provides an update on use of the moss cutter.

Contacts: Brian Mattos, Park Forester, Yosemite National Park, (209) 379-1113, brian_s_mattos@nps.gov; Jim Pendleton, Manager, Talent Irrigation District, (541) 535-1529, tid@talentid.org.

Southeast Region

The Southeast Region of the National Park Service has very few areas that make use of an open-graded mix, and the region's Transportation Program Manager reports no problems with moss growth. Our contacts offer the following suggestions for treatment in areas that do experience moss growth:

Treatment	Description
Pavement mix selection	Avoid the use of open-graded mixes in areas that do not get a lot of traffic.
Glyphosate	(This suggestion was offered by the Natural Resource Specialist at the Natchez Trace Parkway.) Two applications per year of this herbicide should be adequate to kill moss. Glyphosate is the active ingredient in commercial herbicides such as Roundup. See Related Resource below for more information.

Related Resource:

Glyphosate: Roadside Vegetation Management Herbicide Fact Sheet, Washington State Department of Transportation, February 2006.
http://www.wsdot.wa.gov/NR/rdonlyres/A72C98BF-88CD-4BAA-9B0F-5BB709A0C564/0/glyphosate.pdf

This fact sheet was developed by Oregon State University and Intertox Inc. to aid in understanding the risks associated with pesticide use in WSDOT's Integrated Vegetation Management program. The document provides application rates and use patterns and an assessment of risks to human health, wildlife and aquatic areas.

Contacts: Kent Cochran, Transportation Program Manager, Southeast Region, National Park Service, (404) 507-5725, kent_cochran@nps.gov; Barry M. Boyd, Chief of Maintenance, Natchez Trace Parkway, (662) 680-4020, barry_boyd@nps.gov.

State Agencies

We contacted representatives of four states with climates conducive to moss growth on pavement—Florida, Louisiana, Oregon and Washington—and provide the results of discussions with Oregon and Washington State DOTs below. Our contacts at Florida and Louisiana DOTs report no experience with moss growth on open-graded pavements. We also include recommendations from a former Mississippi DOT employee, and begin our discussion with information provided by Caltrans staff with knowledge of the moss growth on District 1 pavements and ideas for possible treatment.

Caltrans

Our District 1 contact suggests the treatment options below for possible further investigation.

Treatment	Description
Augmenting road striping paint with elemental zinc	As zinc leaches out of road striping paint, it might hinder the growth of moss on the highway in a manner similar to how galvanized metal that leaches zinc controls moss on a roof. It is not clear if this is an environmentally friendly option. See Related Resources below for information about metal leaching.
High-pressure, low-volume power washer	A small-scale test of this mechanical method involves the use of a portable power washer to determine how much pressure is needed to remove moss when moving along at a reasonable rate of speed (that is, 10 mph). If this test proves successful, a high-pressure pump on a spray truck could be used, with the existing main tank supplying the pump. A moveable arm on each side of the truck could be mounted to support a small boom with enough nozzles to simultaneously treat a band along the centerline and the fog line of a two-lane highway. The trailer used by bridge crews for power washing might also be appropriate for this application.
Shielded high-intensity ultraviolet light	This light source might burn off moss or delay its growth by triggering a negative phototrophic response. High-intensity ultraviolet light is used to treat recirculating water in greenhouses to remove algae and fungi.
Infrared heater	An infrared heater is used to direct a propane flame at a ceramic or metal plate, which radiates heat onto the moss. Other applications involve the use of water and intense heat in an enclosed space. See Related Resources below.

Treatment	Description
White fog lines	If moss is not present on the white fog line, or is growing more slowly than in other areas, perhaps the paint has a retarding effect. Portions of the less traveled areas might be painted white to inhibit moss growth and provide for better traction.

Mr. Bongio notes the following treatments might resolve the problem of moss growth but are not appropriate for application in District 1.

Treatment	Description
Daylighting the road	Removing trees shading the road is recommended as a way to inhibit moss growth; however, this treatment would not be appropriate for the areas where moss is growing in District 1.
Road salt	Road salt kills moss while also treating snow and ice conditions, but it lacks the environmentally friendly characteristic needed for an effective long-term moss remover/retardant.

Related Resources:

Metal Leaching Versus Antifoulant Control Efficacy, Zebra Mussel Research Program, U.S. Army Corps of Engineer Waterways Experiment Station, Technical Notes, November 1994.
http://www.intmetl.com/zebra_mussel.htm
This web site describes how paint used as an antifouling coating is used to prevent the growth of organisms such as barnacles and zebra mussels on surfaces of vessels and stationary structures. The coatings contain a material that is toxic to the fouling organism. The same principle relates to the use of zinc in road striping paint to impede moss growth.

Sunburst Thermal Weed Control Equipment Technology, Sunburst Inc., undated.
http://www.thermalweedcontrol.com/SunburstTechnology.pdf
From page 1 of the PDF:

> Sunburst's unique, proprietary equipment applies a thin film of water to unwanted vegetation and then subjects these plants to at least three forms of intense heat in an enclosed space (1. infrared energy; 2. turbulent hot air—between 800°F & 2000°F; and 3. boiling water— most of the water sprayed on the surface of leaves and stems prior to heating them is vaporized under the housing).

The vendor notes this on page 2 of the PDF with regard to application rates:

> Under average routine maintenance conditions (i.e., when controlling seedling vegetation on sites that receive regular vegetation management treatments), 1-4 applications per year can keep areas virtually weed free (site conditions and an individual's standards or goals for weed control will determine the actual number of treatments needed).

Contact: Domenic Bongio, Landscape Specialist, Caltrans District 1, (707) 445-6391, domenic_bongio@dot.ca.gov.

Mississippi

Our contact at the Natchez Trace Parkway notes that during his previous tenure with Mississippi DOT the agency placed few sections of open-graded friction courses. He states that cracks and other fissures in

asphalt can fill with wind-borne fines and hold moisture, making these areas ripe for the growth of mold and moss.

Contact: Barry M. Boyd, Chief of Maintenance, Natchez Trace Parkway, (662) 680-4020, barry_boyd@nps.gov.

Oregon

Our discussion with an Oregon DOT Research Coordinator focused on ODOT's experience with moss on roadways with chip seal treatments, not the open-graded asphalt of particular interest to Caltrans.

Like Caltrans, ODOT has identified moss growth on roads in wet, shaded areas. One of these areas is on Oregon Route 138 out of Roseburg in southern Oregon. Moss growth is particularly significant on a one-mile segment, though is present on approximately 20 miles of Route 138 in this area.

In extreme cases, the moss growth covers paint markings and leaves only the wheel path visible. As ODOT considers making greater use of chip seals as a preventive maintenance measure for its highways, this moss growth presents a concern with regard to how to economically and effectively remove moss to prepare pavements for chip sealing. A key question for ODOT: Is this moss growth the result of a failure in the chip sealing process or a failure of the pretreatment methods used to remove moss before applying the chip seal?

Grinding the top 3 to 4 inches of asphalt to prepare for an overlay has proven successful in avoiding a recurrence of moss growth. However, an asphalt overlay of this depth is expensive. More typical are the pretreatment options used to prepare for chip sealing: minimal grinding of 1 to 2 inches or surface scraping of approximately 1/2 inch. Wire brushing and pressure washing have also been tried with mixed results. Despite the wire brushing, moss was observed to continue to grow in the minute cracks of the pavement under the chip seal.

To keep costs in check, ODOT is interested in identifying the minimum level of surface treatment that would remove the moss without significant surface thickness treatment or removal. ODOT might consider other options to remove moss in preparation to chip seal, including:

- Environmentally friendly alternatives such as ionized water (see Related Resource below for more information), baking soda, vinegar and biodegradable fatty acids.
- High pH alternatives (for example, lime).
- Decreasing water through drainage.
- Increasing sunlight using daylighting measures (removal of trees and shrubs).

At this time, it is unclear whether moss growth is the result of chip seal application error or simply aggressive moss growth that would occur regardless of the pavement preparation used. Among the questions ODOT's research staff is considering:

- Is the temperature used for the chip seal process high enough to inhibit moss growth?
- Is the wire brushing done to prepare the pavement for chip seal sufficient? Or is it necessary to prepare the roadway by grinding and then placing an asphalt overlay?
- Should chip sealing be avoided in shaded areas?

Related Resource:

"Applications of Electrolyzed Water in Agriculture & Food Industries," Muhammad Imran Al-Haq, Junichi Sugiyama, Seiichiro Isobe, *Food Science and Technology Research*, Vol. 11, No. 2, 2005: 135-150.

http://www.jstage.jst.go.jp/article/fstr/11/2/135/_pdf
The authors describe the benefits of electrolyzed water (EW), the product of a concept developed in Japan that has garnered worldwide interest. EW may be produced using common salt and an apparatus connected to a power source. In addition to its use as a sanitizer for fruits, utensils and cutting boards, the authors present acidic EW as a cost-effective and environmentally friendly alternative that can be used as a contact fungicide on plant surfaces and for general sanitation in greenhouses.

EW is generated in a cell containing inert positively charged and negatively charged electrodes separated by a membrane or diaphragm. An electrical current passes through the EW generator, and a saturated sodium chloride (potassium chloride and magnesium chloride are also mentioned by the authors) solution and tap water from a supply line are simultaneously introduced into the equipment. The cell electrolyzes the water, resulting in two types of water possessing different properties:

- An electrolyzed basic solution that has strong reducing potential and can be used as a cleaning solution.
- An electrolyzed acid solution with a strong oxidation potential and bactericidal effect that can be used as a disinfectant. This solution is an alternative to chlorine-based compounds for killing bacteria.

Contact: Jon Lazarus, Research Coordinator, Construction, Maintenance and Operations, Oregon Department of Transportation, (503) 986-2852, jon.m.lazarus@odot.state.or.us.

Washington

Our contacts report that open-graded pavement is rarely used in Washington, noting that the studded tires used during Washington's winters eat up open-graded pavements. Dense-graded pavements have provided much better performance.

Moss has been identified growing between the asphalt shoulder and concrete pavement. While unattractive, this joint growth has not presented problems, and Washington DOT has not made an attempt to remove it. If moss were present in the travel lanes and presented concerns about friction, efforts would be made to remove it.

The state's Pavement Engineer notes that pressure washing has been used by the city of Olympia to remove isolated areas of moss from structures or pervious concrete pavement (sidewalks, not roadways).

Contacts: Kim Willoughby, Research Manager, Materials and Construction, Bridges and Structures and Maintenance, Washington State Department of Transportation, (360) 705-7978, willouk@wsdot.wa.gov; Jeff Uhlmeyer, State Pavement Engineer, Washington State Department of Transportation, (360) 709-5485, uhlmeyj@wsdot.wa.gov.

Alternative Methods for Roadside Vegetation Control

Given the lack of recommendations in the literature for the environmentally friendly removal of moss on open-graded asphalt pavement, we looked for practices used to control roadside vegetation that might have some applicability for the moss growth identified in District 1. Below we highlight reports and tools from five state DOTs—California, Massachusetts, New York, Oregon and Washington—that examine alternative methods for control of roadside vegetation, sometimes comparing the alternatives to synthetic treatments.

Background Information

The reports we highlight in this section examine a variety of naturally occurring compounds that are used to control roadside vegetation. The web site below provides links to fact sheets about the active ingredients used in many of these products.

> **Biopesticide Active Ingredient Fact Sheets**, U.S. Environmental Protection Agency.
> http://www.epa.gov/oppbppd1/biopesticides/ingredients/index.htm
> *From the web site*: This collection of fact sheets contains chemical specific information about biopesticide active ingredients. Additionally, some of the fact sheets include a detailed technical document, bibliographies, regulatory history, Federal Register notices, and/or registrant and product lists.

California

Exploring Alternative Methods for Vegetation Control and Maintenance Along Roadsides, Final Report, Caltrans, Project Identification # F2000EN217, February 14, 2003.
http://dot.ca.gov/research/researchreports/reports/2003/alternative_vegetation_control_final_report.pdf
This study examined alternative methods and materials for roadside vegetation management and maintenance with the use of a literature search and field studies. Among the alternatives investigated: bioherbicides, ultraviolet light, the combination of mechanical and herbicide treatments, steam, natural-based products and flaming.

Researchers concluded that the alternatives for controlling roadside vegetation are not as effective and are more costly than standard synthetic herbicides. Findings include the following:

- Ultraviolet light to burn foliage and the combination of mechanical and herbicide treatments require liability insurance or large capital investments.
- Steam and bioherbicides, which require more detailed and long-term study and require major changes in current protocols, are less likely to succeed.
- One or two applications of a flame treatment controlled vegetation, but the cost of gas, labor and the application speed prohibits the use of this technique on a large scale.
- Natural-based products are the most easily substituted materials for currently used synthetic herbicides. However, multiple applications—from three to five—and higher volumes are required to achieve results comparable to synthetic alternatives (for example, glyphosate) and do not result in 100 percent control.
- The natural-based product Bioganic, with the active ingredient clove oil (or eugenol), showed good vegetation control after one year and proved to be more effective at coastal locations.
- After two years of field studies, researchers noted that additional studies are needed to improve the potential for success of alternative treatments.

Roadside Management Toolbox, Caltrans.
http://www.dot.ca.gov/hq/LandArch/roadside/index.htm
This web-based decision tool provides information about the management, maintenance and control of vegetation on roadsides and compares alternative practices.

Massachusetts

Herbicide Alternatives Research, Massachusetts Executive Office of Transportation and Public Works, Report Number SPRII03.23, July 2008.
http://www.mhd.state.ma.us/downloads/manuals/rpt_herbicides_alternative.pdf

Over a two-year study period, researchers compared the effectiveness of alternative herbicide chemicals and mechanical methods with conventional herbicidal treatment for the management of roadside vegetation. Selected alternative herbicides included citric acid and acetic acid products; pelargonic acid; clove oil; limonene (a citrus-derived product); and corn gluten meal. Alternative mechanical treatments included heat applications such as steam or flame. Testing was done on roadside and field locations and in off-season greenhouse locations.
Results suggest that, compared to conventional herbicides, the alternative methods chosen for research were less effective and more costly. Researchers note that some alternative practices could be integrated with application of conventional herbicides to reduce their overall use and recommend further research in this area. Specific findings include:

- Repeated applications of the alternative herbicides and the mechanical methods of steaming or burning would be necessary to obtain results achieved by conventional herbicides.
- The material cost of the alternative herbicides was more than the conventional herbicides—sometimes substantially more. The need for repeated applications of the alternative herbicides further increases their cost.
- The conventional herbicides glyphosate (Roundup) and glufosinate-ammonium (Finale) consistently provided acceptable to excellent control of vegetation with one application, with the former performing better overall than the latter.

New York

New Alternatives to Synthetic Herbicide Techniques for Treating Roadside Vegetation, Final Report, New York State Department of Transportation, SUNY-ESF Project Report #5, December 2005. http://www.utrc2.org/research/assets/94/herbicides5_1.pdf
This report is the result of the final phase of a four-phase project to assess alternatives to synthetic herbicide use for roadside vegetation control. Earlier phases of this research selected a small number of promising treatments for a more detailed review. The four natural herbicides examined in this report include:

- Finale, a nonselective herbicide that inhibits photosynthesis, was found to produce poor long-term control when compared to synthetic herbicides. A mixture of Finale with certain synthetic herbicides may be more effective.
- Burnout II is primarily a blend of vinegar and lemon juice. Researchers found no documentation on the effectiveness of this product.
- EcoEXEMPT is a nonselective herbicide that "burns" annual and perennial broadleaf and grass weeds with the active ingredients phenethyl propionate and eugenol (clove oil). Researchers found no scientific evidence on the effectiveness of this natural herbicide.
- Scythe herbicide is a fatty acid-based, nonselective herbicide with the active ingredient pelargonic acid. Considered a "burndown" contact herbicide and applied as a spray for the control of annual weeds, Scythe was found to be less effective than Finale.

Developing a Cost-Effectiveness Model for Research, Development, and Application of Herbicide and Non-Herbicide Vegetation Management Treatments for Roadside Rights-of-Way, New York State Department of Transportation, SUNY-ESF Project Report #4, December 2005. http://www.utrc2.org/research/assets/94/herbicides4_1.pdf
Researchers constructed a cost-effectiveness evaluation matrix based on expert opinion to compare herbicide and nonherbicide alternatives for managing roadside vegetation. Expert opinion from this pilot-scale study suggests that:

- Conventional herbicide treatments are more cost-effective than nonherbicide treatments.

- Future work in nonherbicide alternatives used in the operational zone of roadside rights of way should be focused on the use of bioherbicides and mycoherbicides (bioherbicides based on a fungus).

Alternatives for Treating Roadside Right-of-Way Vegetation: Literature Review and Annotated Bibliography, New York State Department of Transportation, SUNY-ESF Project Report #1, December 2005.
https://www.nysdot.gov/portal/page/portal/divisions/engineering/environmental-analysis/repository/c-02-09-1.pdf
Researchers conducted a literature review that identified 81 references on the topic of alternatives to managing roadside vegetation. The results of this review were used to identify a small group of alternative methods for further examination that are presented in SUNY-ESF Project Report #5 (see above).

Oregon

Evaluation of Infrared Treatments for Managing Roadside Vegetation, Oregon Department of Transportation, FHWA, Report Number FHWA-OR-RD-01-06, December 2000.
http://ntl.bts.gov/lib/10000/10500/10534/infrared_veg.pdf

Note: Sunburst Inc. provided the infrared unit used for this project. See page 10 of this Preliminary Investigation for more information about the Sunburst product.

Researchers investigated the use of infrared technology to determine its viability as a component of Oregon DOT's strategy to manage roadside vegetation. In this application, infrared technology applies intense heat generated by liquid propane. Repeated treatments at regular intervals deplete the root reserves of established plants and lead to their decline and eradication. Infrared treatments were applied at three rates (eight, six and four treatments per year) along Oregon highways from November 1996 through June 1999. Researchers found that three to four infrared treatments per year should be sufficient in most conditions and climates where there is light vegetation and low to moderate growth rates.

Washington

Assessment of Alternatives in Vegetation Management at the Edge of Pavement, Washington State Department of Transportation, Report Number WA-RD 736.1, May 2010.
http://www.wsdot.wa.gov/research/reports/fullreports/736.1.pdf
This report is a follow-up to the December 2005 report (see below) that began an examination of the maintenance options for the bare-ground strip on road shoulders in Washington. While not directly applicable to the removal of moss from pavement, the information contained in this report with regard to the costs, outcomes and recommendations resulting from 43 individual case studies on Washington state highways may be of interest to Caltrans.

See page 75 of the PDF for a discussion of field tests conducted during the period 2006 through 2009 that used nonselective herbicides—including glyphosate alone and in mixtures—to maintain the bare-ground strip. Appendix B, which begins on page 87 of the PDF, provides a breakdown of manpower and equipment required, and the hours and costs associated with each alternative treatment.

Assessment of Alternatives in Roadside Vegetation Management, Washington State Department of Transportation, Report Number WA-RD 621.1, December 2005.
http://www.wsdot.wa.gov/research/reports/fullreports/621.1.pdf
Through use of a literature review and interviews with experts, this study explored alternatives to the use of an annual application of herbicides for removing vegetation in the bare-ground strip immediately adjacent to the pavement edge (what Washington State DOT calls "Zone 1").

Researchers noted that many other state DOTs and local agencies do not maintain a bare-ground strip on all road shoulders, and there is little data on the relative safety, cost-effectiveness and environmental impacts of the various pavement edge maintenance practices. Researchers recommended a follow-up study to field-test alternatives for maintenance of vegetation at the pavement edge. The results of those field tests are presented in the May 2010 report above.

A list of physical or biological vegetation control alternatives begins on page 56 of the PDF. Among the options: hot water, steam and foam; radiant heat; controlled burning; salt water; and mild acids (generally vinegar or acetic acid spray).

A review of nonconventional herbicide alternatives begin on page 58 of PDF. Among those presented are:

- Organic herbicides such as crop oils, corn gluten, pine oil and plant essences.
- Postemergent herbicides that are selectively applied after vegetation has partially developed.
- Nonresidual herbicides that rapidly decompose and have no significant ongoing action or presence.

Application guidelines for these alternatives were not available at the time of publication.