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Assessment of Alternatives in Roadside Vegetation Management

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16. ABSTRACT

This study was conducted for the Washington State Department of Transportation (WSDOT) to explore both the need for and the variety of alternatives to the use of an annual application of herbicides for removing vegetation in the area immediately adjacent to the pavement edge. Our study approached these questions in two different ways, developing both a literature review and a set of interviews with people who have specific knowledge or views of these issues.

We conducted interviews with three groups of people to identify issues, maintenance alternatives, and significant literature references: (1) staff at other federal, state, and county transportation agencies, (2) staff and volunteers who work with advocacy groups, and (3) researchers at academic institutions who specialize in related areas. Our literature review contains a set of citations that present related management issues and alternative practices. The abstracts for these references were included when available.

To summarize what we learned from the interviews and literature sources, we developed a decision framework that could be used to guide WSDOT district maintenance staff in formulating management plans for vegetation. The decision framework differs from current practice primarily in that it begins with the assumption that maintenance of the area immediately adjacent to the pavement is not necessary unless some particular, observable condition triggers the need for such maintenance.

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EXECUTIVE SUMMARY

The Washington State Department of Transportation (WSDOT) has traditionally used herbicides, along with mechanical means such as mowing, trimming, and grading, to manage vegetation along highways. Some citizens are concerned with herbicide use because of possible impacts on human health and the environment. Historically, the majority of WSDOT's herbicide use has been focused on the road shoulder directly adjacent to the pavement edge. WSDOT has typically maintained a 2- to 4 foot strip next to the pavement as a vegetation-free zone (referred to as Zone 1) through annual herbicide applications. This is done for a variety of reasons, including but not limited to pavement preservation, stormwater drainage, cost-effective maintenance, safety as related to maintenance and traffic operations, and reduction of the potential for roadside fire starts. WSDOT maintains a website that describes its maintenance responsibilities, practices, and other research on its vegetation management program at www.wsdot.wa.gov/maintenance/vegetation/.

Although alternatives exist to the maintenance of Zone 1 with herbicides, there are also questions regarding the relative safety, cost effectiveness, and environmental impacts of some of these alternatives. While WSDOT personnel have begun experimenting with alternatives and have conducted some research and cost analyses of Zone 1 maintenance versus vegetated shoulder approaches, a more comprehensive analysis needs to be completed that examines a wider spectrum of costs and benefits to guide future WSDOT decision making.

This report was prepared by two researchers in the Department of Landscape Architecture at the University of Washington who were approached by WSDOT staff to conduct research and participate in a Working Group. The Working Group was composed of representatives of various organizations or individuals that have an interest in WSDOT's policy for vegetation management at the edge of pavements along state roads; representatives of county, state, and federal agencies involved in roadside management or its environmental effects; and WSDOT staff. The UW researchers were guided by this group in conducting literature reviews and interviews on the subjects of roadside management issues and practices, and they concluded their work by developing a formalized decision framework to help WSDOT staff develop a consistent approach to vegetation management at the pavement edge.

The first section of this report presents the results of the literature review. Complete citations (and abstracts if available) are listed in Appendix A. The review was conducted between August 2004 and February of 2005 using keywords from two general categories: (1) roadside vegetation management issues in Zone 1 (a term used by WSDOT staff to refer to the maintenance of a vegetation-free zone in the first 2 to 4 feet adjacent to the pavement along state roads); and (2) alternative practices that have attempted to address those issues. All of the relevant databases maintained by the University of Washington libraries were utilized for the search, along with on-line research databases maintained by federal agencies such as the national Transportation Research Board (TRB). An initial set of references was expanded through interviews with experts from around the country, each of whom was asked whether they were

familiar with any key research publications on the major issues generated by the Working Group.

Our key findings in the literature review were as follows: (a) alternative maintenance practices are being utilized in many parts of the U.S. and also in northern Europe, but very little comparative cost information has been published at this time; (b) no one seems to have yet documented and published successful planting specifications for the immediate road shoulder that use primarily native plants and would have no adverse effects or not require mowing; (c) although ponding on the roadway due to dense, low vegetation along the pavement edge is known to occur, other regions have not published research related to pavement life and traffic safety problems associated with this phenomanon; (d) although some recent studies suggest that there may be previously unknown potential impacts from herbicides currently used by WSDOT in Zone 1 because of either their active ingredients, their surfactants, other chemical components, or as a result of combinations with other chemicals, federal and state regulations are supported by many other studies that have demonstrated that the herbicides currently used by WSDOT for maintenace of Zone 1 in Western Washington are associated with relatively low environmental risks.

We also conducted a series of interviews between August of 2004 and January of 2005, speaking with transportation department staff in U.S. states that are considered progressive in their maintenance of roadsides, and with members of the WSDOT Working Group. In addition, we spoke with transportation department staff in the Canadian province of British Columbia. In each interview, we asked about the person's experience with key maintenance issues and alternatives identified by the Working Group

at its first meetings. We wanted to determine whether the interviewees had confronted key issues such as alternatives to the maintenance of Zone 1 with herbicides, ponding of runoff on the roadway surface, pavement break-up that might be caused by plant roots or shoots, increased costs of mowing versus herbicide use, selection of native plant mixes that could tolerate the difficult growing conditions next to the pavement edge, or alternative maintenance practices used to contain or reduce plant growth.

Our key findings in the interviews were as follows: (a) roadside vegetation management staff in Montana's state Department of Transportation believe that they have experimented successfully with a combination of topsoil amendments and a seed mix that uses mostly native plants along the pavement edge, although this success has not been formally evaluated; (b) California has a study under way on the use of native plants next to the pavement edge, and has developed a roadside management "tool kit" that documents alternative treatments being evaluated by Caltrans; (c) most states seem to be continuing to use herbicides in localized or selective/spot applications while working to develop native plant mixes that require less growth maintenance; (d) a smaller number of agencies (state and county) do not use herbicides for maintenance of Zone 1 and rely primarily on mowing for growth control. The interviews suggested that several states, California in particular, will soon release new publications documenting their experiments with new low-maintenance, native seed mixes for planting adjacent to the pavement edge.

The final chapter of this report presents a decision framework that incorporates all of the information we obtained in our search of the literature and through interviews. This is meant as a tool for WSDOT maintenance managers, who can use it to think

through alternatives to their current approach to maintaining vegetation at the edge of pavement. This decision-support tool begins with the assumption that there may be no need to maintain a vegetation-free zone at the edge of the pavement (i.e., a Zone 1 condition). It is assumed that maintenance of a vegetation-free zone adjacent to the pavement is not necessary unless some other observed factor (for example, frequent fire starts, ponding of runoff on the road surface, potential traffic and safety impacts from alternative practices, or disruption of visual sightlines) raises the need for maintenance. If a need for maintenance of Zone 1 is observed, then the supervisor may consider if there are any practical alternatives to the practices of using routine pre-emergent and/or non-selective herbicide applications. Alternatives could include mechanical tilling or grading, use of artificial weed barriers, or an expansion of the pavement area with a permeable pavement type, among other possible options. If the maintenance of Zone 1 is not required but there is a need for some type of vegetation control, the supervisor may consider a range of alternatives to achieve the needed level of control. Alternatives for this type of maintenance include mowing, spot treatments (with herbicides or mechanical means), or modification of the soil/growing medium, among other options. In either case the local maintenance manager is encouraged to select the alternative method that fits the available maintenance budget, is most cost effective, and has the fewest negative side effects (including worker safety). As alternative practices are implemented, WSDOT maintenance managers have the opportunity to learn from and document their successes in their own maintenance areas. This documentation and experimentation process is essential in order for WSDOT to identify practices that are the most cost effective and have the fewest negative side effects. No better resource for this information exists than

one that can be created over time in each WSDOT maintenance region. Field observation and documentation of alternative practices by staff or consultants will be an essential component of the success of this decision framework.

This report is intended as an initial step in developing a successful program of field observations and management case studies that can lead to increased knowledge and experience with alternative approaches to roadside vegetation management by the Washington State Department of Transportation. While it does not include summaries of field observations, the literature and interview results may be helpful in determining which variables are likely to be of most concern in future field observation studies. The decision framework chapter is intended to support maintenance managers in choosing where and when to continue to maintain Zone 1, and should be adapted with new knowledge about the success or failure of specific techniques.

We would like to thank WSDOT staff and all of the other members of the Working Group for their input to this report.

CHAPTER 1
INTRODUCTION

The Washington State Department of Transportation (WSDOT) primarily uses a combination of herbicides and mechanical means such as mowing, trimming, and grading to manage vegetation along highways. The most concentrated effort in roadside vegetation management occurs immediately adjacent to the highway pavement. Historically, WSDOT has relied on the annual application of herbicides to maintain a vegetation-free strip, referred to as Zone 1, along all sections of highway pavement. This has been done for a variety of reasons, including but not limited to concerns about pavement preservation, stormwater drainage and pollution filtration, cost-effective maintenance, safety as related to efficient maintenance traffic operations, and reduction of the potential for roadside fire starts.

The purpose of this study was to identify economically and environmentally sound alternatives to the practice of maintaining Zone 1 through routine, annual herbicide applications, and to analyze and organize potential alternative practices in relation to maintenance objectives (or decision factors) as they occur along varying sections of highway. Some of the findings and analysis contained in this report may apply to highway sections in the more arid ecosystems on the east side of the state. However, the focus and application is on roadsides in Western Washington in relation to factors such as higher precipitation, specific vegetation types and growth rates, and generally higher traffic volumes.

WSDOT practices for the maintenance of vegetation along the edge of pavement have evolved over the years in response to new technology and advancement in

environmental science. Up until the early 1990s, WSDOT maintained a vegetation-free strip from the edge of pavement out through the bottom of the ditch line or to the toe of the roadway subgrade, at an average width of 8 to 12 feet. In 1992 the agency conducted a review of this practice and determined that Zone 1 may not be required in all locations and that when required, the optimum width should be 2 to 4 feet. In Western Washington, the maintenance of Zone 1 was typically achieved with a combination of herbicides applied directly to the soil in a solid band along the edge of pavement each year in the spring. The herbicides used for this purpose usually included one or more pre-emergent, soil residual products that were intended to lock up in the top of the soil profile and prevent any seed germination or vegetative growth. These pre-emergent herbicides were typically mixed with a non-selective, post-emergent herbicide to remove any vegetation top growth present at the time of application.

In 2003 the U.S. Environmental Protection Agency conducted a re-evaluation of herbicide products in relation to potential impacts on aquatic species and found that the primary pre-emergent herbicide used by WSDOT in maintenance of Zone 1 (diuron) may affect aquatic species and ecosystems. As a result of this finding, WSDOT discontinued the use of this product on the west side of the state. Without the use of diuron over the past two years, the maintenance of Zone 1 with herbicides has proven less effective. This factor, combined with heightened public concern over the potential toxicity of herbicides to both humans and the environment, prompted the search for alternative practices and development of the decision process contained in this report.

WSDOT maintains a website that describes its maintenance responsibilities, practices, and other research on its vegetation management program at www.wsdot.wa.gov/maintenance/vegetation/.

Although alternatives exist to the maintenance of Zone 1 with herbicides, there are also questions regarding the relative safety, cost effectiveness, and environmental impacts of these alternatives. While WSDOT personnel have begun experimenting with alternatives and have conducted some research and cost analysis of the Zone 1 versus vegetated shoulder approaches, a more comprehensive analysis needs to be completed that examines a wider spectrum of costs and benefits to guide future WSDOT decision making.

This report was prepared by two researchers in the Department of Landscape Architecture at the University of Washington who were approached by WSDOT staff to conduct research and participate in a Working Group. This group was composed of representatives of various organizations and individuals with an interest in WSDOT's policy for vegetation management at the edge of pavements along state roads; representatives of county, state, and federal agencies involved in roadside management or its environmental effects; and WSDOT staff. Members of the working group and their affiliations or area of expertise are listed in Appendix C. The UW researchers were guided by this group in conducting literature reviews and interviews on the subjects of roadside management issues and practices, and they concluded their work by developing a formalized decision framework to help WSDOT staff develop a consistent approach to vegetation management at the pavement edge.

Chapter 2 of this report presents the summarized findings of the literature review.Complete citations (and abstracts if available) from the literature review are included in Appendix A. The review was conducted between August 2004 and February of 2005 using keywords from two general categories: (1) roadside vegetation management issues in Zone 1 (a term used by WSDOT staff to refer to the maintenance

of a vegetation-freezone in the first 2 to 4 feet adjacent to the pavement along state roads); and (2) alternative practices that have attempted to address those issues. All of the relevant databases maintained by the University of Washington were utilized for the search, along with on-line research databases maintained by federal agencies such as the national Transportation Research Board (TRB). An initial set of references was expanded through interviews with experts from around the country, all of whom were asked whether they were familiar with any key research publications on the major issues generated by the Working Group.

We also conducted a series of interviews between August of 2004 and January of 2005, speaking with transportation department staff in U.S. states and selected Candian provinces that are considered progressive in their maintenance of roadsides, and with members of the WSDOT Working Group. In each interview, we asked about the person's experience with key maintenance issues and alternative practices for maintenance of vegetation at the edge of pavement. Interview findings are summarized in Chapter 3.

The final chapter of this report presents the Decision Framework that incorporates all of the information we obtained in our search of the literature and through interviews. This is meant as a tool for WSDOT maintenance managers, who can use it to think through alternatives to their current approach to maintaining Zone 1.

A group of WSDOT subject matter experts and a group of external stakeholders were also invited to review a draft of the final report and provide comments. A list of individuals included in this technical review committee and their area of expertise or affiliation is also included in AppendixC.

CHAPTER 2
LITERATURE REVIEW

This review was undertaken between August 2004 and January 2005 to identify existing literature that is relevant to the decision factors listed by the WSDOT Working Group or to the alternative roadside vegetation management practices identified by the Working Group. We made use of several research databases, including the National Transportation Research Board database. We also asked for references in interviews with people who have professional knowledge related to these areas of interest, and with members of the WSDOT Working Group that was formed to support this research.

The review began with a brainstorming session at the first meeting of the Working Group in August of 2004. Members of the group were asked to brainstorm a list of issues that they thought should matter to WSDOT's decision making about how it maintains vegetation along the edge of pavement on state roads. Then the group considered the question of what design and maintenance practices might exist that could function as alternatives to routine annual herbicide use for maintaining vegetation at the roadside edge. Both of these unedited brainstormed lists are included as Tables 2.1 and 2.2 in Appendix B. In order to accomplish a literature review within the time frame of this study, we prioritized our review of published literature that might be relevant to the decision factors by focusing most on the major categories of concerns generated by the Working Group. These major concerns were: ponding of stormwater runoff as a result of vegetation being next to the paved roadway surface, new research about the risks associated with the use of relatively low-toxicity herbicides, the dynamics of fire starts, wildlife interactions with vegetation along the roadside, and the relative effectiveness and

safety of alternative practices. A summary for each of these high-priority areas of interest is presented below.

SUMMARY OF LITERATURE ON DECISION FACTORS

Drainage and Roadside Vegetation

Our interviews with WSDOT field staff supported the observation made by some Working Group members that water may pond and channelize as a result of debris accumulation at the edge of pavement, and that debris may accumulate as a result of the presence of vegetation at the edge of pavement. The published literature on this subject is unfortunately very sparse. The idea that roadside vegetation causes ponding was questioned by Dunlap (1991) in a small pilot study, but there is no other evidence of formal research on this issue. The Dunlap study alone did not focus directly on this issue, and does not constitute a compelling test of this relationship. The interview data we gathered provides more information about stormwater ponding in relation to roadside vegetation, but this information sometimes provides conflicting conclusions. This appears to be an important area for more research on the specific effects of roadside vegetation in the climatic context of Western Washington. Some interviewees suggested that the absence of snow-removal activities may allow more debris to pile up at the edge of the pavement, creating special stormwater ponding problems in relatively snow-free areas. New research in Western Washington should consider this possible relationship between a lack of snow removal and the build up of debris that creates a drainage barrier. Roadside vegetation at the edge of pavement may or may not play an explicit role in this debris accumulation, and there is no clear conclusion among roadside managers or researchers that it does or to what degree. What is clear is that ponding and

channelization of runoff have been observed on the edge of roadways in Western Washington in association with debris build-up at the edge of pavement.

Literature on the Associated Effects of Relatively Low-Risk Herbicides

Practices for the maintenance of Zone 1 typically involve an annual application of herbicides. This maintenance technique has several advantages. It is familiar to WSDOT field staff, for example, and some would argue that it is the most cost-effective approach for controlling vegetation immediately adjacent to the pavement edge. The arguments for and against the use of this technique address both cost-effectiveness and environmental risk. WSDOT has invested considerable effort in analyzing the impacts and risk from the use of herbicides. An Environmental Impact Statement (EIS) on roadside vegetation management alternatives was completed in 1993. The preferred alternative selected as a result of this process was application of Integrated Pest Management (IPM) principles through the creation and implementation of locally based roadside management plans. A risk assessment of herbicide use was also produced as part of the EIS (Roadside Vegetation Management Programmatic EIS 1993) in relation to WSDOT product use and application methods. This risk assessment was recently updated (2003/2005 update by Intertox) to include consideration of all scientific study done on herbicides and application methods currently used by WSDOT. As a result of this recent analysis and current study of selected herbicides by the U.S. Environmental Protection Agency (EPA) and the National Marine Fisheries Service, WSDOT has implemented agency policy decisions limiting the use of several herbicides shown to have potential impacts on aquatic species. With regard to herbicides used in the maintenance of Zone 1 and these

recent findings, WSDOT discontinued the use of the herbicide diuron in Western Washington as of 2003.

Because the use of diuron has been discontinued, the primary herbicide now used for maintenance of Zone 1 is glyphosate. We considered it important, therefore, to conduct a basic review of the recent literature related to glyphosate, which is considered to introduce relatively low levels of risk to human health and the environment.. Our goal was to review recent articles that might provide valuable information to WSDOT managers about whether new research confirms or contests the notion that relatively low levels of environmental risk are associated with this herbicide.

The literature we found indicates that there is currently very little peer-reviewed evidence of significant risk from toxicity resulting from the use of glyphosate-based herbicides, particularly in the range of rates and application methods used by WSDOT. Recent ecological arguments in favor of the use of herbicides in general (see, for example, Hamilton et al. 1998; Simberloff 2003) present evidence of the need for early control of invasive species in order to establish and sustain native plant communities. In this argument, herbicides are a recommended addition to hand-removal and mechanical techniques that might be used when costs prohibit the use of mechanical methods. Several studies found no effect of glyphosate on soil microbial communities (Busse et al. 2001).

The literature also contains evidence of potential impacts from formulations of glyphosate. These point to the cumulative ecological effects of the active ingredients, and/or the surfactants and other "inert" ingredients. However, the surfactant (POEA), which was shown to increase toxicity in the glyphosate based product "Roundup," is not used in the current formulations of this product that are purchased by WSDOT.

With regard to the overall use of herbicides, arguments against are sometimes based on logical reasoning rather than on the outcomes of specific peer-reviewed scientific studies (see, for example, Steingraber 1997). For example, a common logic-based argument against the use of chemical herbicides is that land managers have an ethical responsibility to protect the health of the most vulnerable humans, whose ability to tolerate exposure to toxic materials has been reduced. Most formal government testing of chemicals appears not to be conducted with an explicit focus on this segment of the human population. Therefore, some conclude that these chemicals can not be used without introducing new potential risks for vulnerable human groups, such as children and adults with compromised health. Similarly, recent writing on decision-making in uncertain conditions argues for a cautious approach to the use of potentially toxic materials, especially in situations where there may be multiple stressors and interactive effects (see, for example, Ricci et al. 2004).

In addition, a growing body of peer-reviewed experimental and observational studies exists in the scientific literature that examines the fate of relatively low-risk herbicides such as glyphosate (see Tsui and Chu 2003; Chen and Hathaway 2004). Some new peer-reviewed evidence, for example, suggests a greater impact on amphibians and soil fauna than was previously expected. In addition, there is evidence that glyphosate reduces the effectiveness of nitrogen-fixing bacteria (Santos and Flores 1995). These studies are limited in number and have not all been replicated by other researchers (see Brust 1990; Relyea 2004; Sih et al. 2004). There are also important differences in whether the research considers only the effects of the active ingredients or the effects of its associated byproducts, surfactants, and other inert ingredients as well. At least one study of herbicide mobility in northern California roadside environments found that one

of the elements of glyphosate decomposition was highly mobile in stormwater runoff, although the herbicide itself was not detected (Huang et al. 2004).

Many of the concerns that are raised by these studies relate to aquatic environments. Although most state roads maintained by WSDOT do not have an aquatic environment adjacent to the pavement, some older roads do have ditches that are affected by maintenance of Zone 1. These ditches are often hydraulically connected to aquatic habitats. In those atypical areas, maintenance of Zone 1 with herbicides could potentially affect aquatic organisms.

Dynamics of Fire-Starts Adjacent to Roadway Paved Areas

Roadside fires are an important hazard that vegetation maintenance practices are intended to reduce. The current literature does not contain much peer-reviewed work on this subject, however. We reviewed two government reports, one from a U.S. Forest Service research center in California produced in 1968 and one from the Texas Transportation Institute published in 1993. Neither of these had results that were specific to vegetation immediately adjacent to the edge of pavement, and the different climate zones involved did not offer information that could translate directly to Western Washington conditions. It was interesting to note that there has been no published research on this subject in Western Washington, and very little in general. This makes it impossible to generalize any observations at this time that might be relevant to the maintenance of vegetation by WSDOT staff in Zone 1.

Interactions between Roadside Vegetation Patterns and Wildlife Habitat Use

The literature on this subject is related to vegetation in highway corridors but does not specifically address vegetation in the area immediately adjacent to the pavement

edge. The most recent comprehensive reference is by Forman et al. (2003). Our review lists a number of other studies that have addressed the issues related to roadside vegetation management in general, notably Clarka et al. (2001), who presented the results of a study that suggested that an insect that is useful as a biological control agent for knapweed should be released into large patches of this plant in order to thrive, rather than in strips of knapweed such as might be found along a roadside. Pauchard et al. (2004) studied the relationship between the spread of invasive plants into areas of high-quality wildlife habitat, concluding that roadsides are a major corridor for the dispersal of invasive non-native plant species and recommending that early detection and removal are critical to preventing this interaction from leading to the decline of quality habitat in non-roadside areas. Rea (2003) studied the relationship between roadside vegetation maintenance and the attractiveness of browse for ungulates, such as moose and deer. He concluded that cutting shrubs in the roadside area in mid-summer produced high-quality browse that ungulates may prefer, creating an attraction that may bring more animals near roads. His suggestion was that shrubs should be cut in early summer to avoid creating an especially attractive food supply for ungulates in roadside vegetation.

Relative Safety of Alternative Practices

One of the considerations for maintenance of vegetation at the edge of pavement is minimization of the time required for maintenance activities focused on this task. Maintenance of Zone 1 with herbicides can be accomplished with one relatively quick (15 mph) pass. By comparison, mowing operations typically move at average speeds of 3 to 5 mph and may be required more than once per year. Vegetation at the edge of pavement may also contribute to a build up of debris and a potential increase in the need to remove edge build up with grading operations. Although we found no documented

research that indicates increased accidents or traffic congestion as aresult of roadside vegetation management activities, the possibility that an increase in the time required for these activities would result in greater potential for impacts on traffic safety and worker safety is of great concern.

SUMMARY OF LITERATURE ON ALTERNATIVE PRACTICES

The literature indicates that there are limited ongoing efforts in other jurisdictions to develop management approaches that integrate road maintenance with vegetation maintenance (see, for example, Webb 2003) by using asset management, geographic information systems, and other tools. There are also a number of U.S. states where efforts are being made to develop vegetation maintenance approaches that focus on the life-cycle costs and benefits of establishing particular plant communities (see, for example, Bruneau et al. 1999, and Brown and Rice 2001). In these cases, as in WSDOT design and maintenance, plant community selection is seen as a maintenance approach as well as a design strategy for roadsides.

In particular, given some of its climatic similarities and an earlier effort to reduce herbicide use along roadsides as a vegetation management approach, California's Department of Transportation (CALTRANS) has some very useful experiences to share. CALTRANS often partners with research scientists at UC Davis, and a research group at UC Davis has recently released a number of studies that might be particularly useful for the Western Washington region (see Young 2004, and Brown and Rice 2001), who studied establishment techniques for native grasses in California roadside environments). Most pertinent, however, is that CALTRANS has developed a resource it calls the "roadside management toolbox," which it is beginning to use to compare different

alternative practices. This toolbox offers an approach to roadside vegetation management that could serve as a model for Western Washington.

In addition, Maine, Minnesota, New York, Oregon, and Vermont appear to be reviewing their vegetation control techniques and experimenting with alternative methods (see Burnham et al. 2003; Edgar 2000; Johnson 2000; LaRoche and LaRoche 2001; Varland and Schaefer 1998; Williams 2003).

Vegetation control and the establishment of desirable species at the pavement edge appear to be linked to compost use by many state agencies (for an early study in Washington, see Hamilton et al. 1998). Compost and soil bioengineering were studied in relation to their cost effectiveness by Hagen et al. (2002). Iowa's DOT has produced a recent (2003) set of research results and recommendations for the use of compost in the roadside environment to improve stormwater runoff quality. Kirchhoff et al. (2002) conducted a large multi-state study of the potential role of compost on highways, with a focus on the quality and availability of composted manure. Sanders (2000) studied the life-cycle costs of using waste tires for rubber landscape mulch in the roadside environments of South Carolina.

Alternative methods for weed control have included steam and "wet infrared" technology.Vermont and Oregon have experimented successfully with new infrared tools for weed control (Burnham et al. 2003; Edgar 2000). Although no cost information was included in these reports, the operations were slow moving and sometimes required more than one treatment in a season.

Establishment of various plants has been studied in the roadside environment, including the use of crown vetch in Maine (LaRoche and LaRoche 2001), the desirability from the highway users' perspective of "park like" plantings of large trees (Hamilton et

al. 1998), and the variations in soil nutrient levels that affect the potential for different plant communities to become established (Stringer 2001).

Decision-making approaches to managing roadside vegetation have been proposed by many public agencies, but a level-of-service analysis for maintenance was conducted by Woods et al (1994) that seems very close to the assessment approach that we have begun to discuss as a "decision framework" within the Working Group. This study developed rapid data collection techniques for roadsides in the state of Texas that use field personnel and various means of recording data. Also, Webb (2003) has proposed an asset-management framework for roadside maintenance in Australia that may offer important concepts for roadside maintenance in Washington State.

The complete list of literature references, including abstracts when available, is contained in Appendix A.

CHAPTER 3
INTERVIEW SUMMARY

Between August of 2004 and January of 2005, we conducted more than 40 interviews with WSDOT staff, the staff of federal agencies and other local or state jurisdictions, consultants and activists concerned about herbicide use and/or roadside vegetation, and university researchers. We tried to focus on speaking with staff at county, state, and federal transportation agencies because we thought they might be more likely to be aware of decision factors and alternative practices that had already been determined to be relevant and useful in practice. We did not pursue interviews in other countries, with the exception of one Canadian province (British Columbia).

Table 3-1. Summary of the organizational affiliations of interview participants

WSDOT staff	Staff of other transportation agencies	Consultants, activists, and staff of other government agencies	University researchers
4	23	13	4

In each interview, we identified ourselves as University of Washington researchers conducting a study for the Washington State Department of Transportation. We used two open-ended questions to invite responses, and we followed each with additional questions that asked for more specific information about what the participant had initially said. Our opening questions were:

(1) Can you tell us what issues you think are most significant in the management of vegetation immediately adjacent to the pavement?

(2) Can you identify any management practices you think have been particularly successful or offer significant promise in the management of this zone?

We also asked questions about two prominent issues that emerged from the discussions of the WSDOT Working Group. The first of these was whether the interviewees were aware of drainage problems occurring in areas where a vegetation-free zone (Zone 1) was not maintained along the roadside, and the second was whether they were aware of a native plant seed mix that would work well in their region as a vegetative cover immediately adjacent to the edge of pavement. In some cases, a wide-ranging conversation occurred during the interview that brought other information to our attention. Significant information gathered through the interviews has been summarized below. We have organized this report by categories of affiliation for each interview participant (i.e., transportation agency staff, other government agency staff, consultant, researcher) in order to avoid identifying the specific people with whom we spoke.

INTERVIEWS OF TRANSPORTATION AGENCY STAFF

We spoke with staff at the state level in British Columbia, California, Colorado, Florida, Idaho, Iowa, Maine, Massachusetts, Montana, Oregon, New York, Utah, Vermont, and Washington. We also spoke to staff at the Federal Highway Administration and at the county level in Washington and Oregon. The most significant issues in the management of roadside vegetation included the efficacy of the management tools, the control of invasive species, driver safety, maintenance crew safety, fire prevention, and cost.

Stormwater Ponding

Ideally, water should flow off of the pavement evenly and infiltrate as soon as possible. Stormwater ponding is a condition in which water collects on the road surface because of inadequate drainage in low-lying areas. Ponding can decrease driver safety

and increase localized channelization and erosion where detained water breaks through blockages in roadside drainage. Many with whom we spoke offered the observation that ponding problems were as much a result of road design as vegetation management regimes. We observed what may be a pattern related to regional climate differences. There is some indication that states and regions where heavy winter snowfalls make roadway plowing necessary have fewer problems with stormwater ponding next to vegetation growth in Zone 1. This may be because the plants are affected by winter plowing and by the removal of sand and debris built up at the road edge (through blading in early spring), and the plants are thinner and/or shorter during the growing season as a result. According to anecdotal information provided by WSDOT maintenance staff, this relationship has also been observed on sections of Washington highways where Zone 1 has not been maintained over the past seven years. They reported that no buildup has occurred on a section of higher elevation roadway that is routinely bladed for snow in the winter; but on a lowland section of highway over the same time period, a 2- to 4-inch berm developed. WSDOT staff also stated that when removal of soil or debris buildup through scheduled grading and removal of debris is required, there are considerable costs and impacts on traffic. This phenomenon has not been studied in the literature on the subject of roadside vegetation maintenance, so no comparisons are available with other states or climate zones.

Several people noted that blading down to the vegetation-free soil seems to produce more erosion, however, and that this erosion often has water quality impacts. It should be also noted that where roads are banked to one side, there is no need to manage the vegetation on the up-slope roadside edge. Likewise, there may be no need to manage the vegetation to allow for drainage where water flows downhill along the road, or where

drainage is contained on the pavment with curb/gutter and catch basins, or where the density of plant cover is low enough to allow for water to leave the road surface unimpeded (e.g., the arid climate of Utah supports a plant cover of approximately 68 percent).

Native Plant Mixes

On the basis of our interviews, it seems likely that the establishment of native plants along the roadside will depend on road design, the level of disturbance, soil quality, how the term "native" is defined with regard to plant species, and the types of maintenance that occur. The interviews suggested that the poor soil of a roadside immediately adjacent to the pavement edge is an environment where the most aggressive and invasive plant species typically colonize. This is especially true in areas where maintenance of Zone 1 with soil residual herbicides has been practiced for a number of years. In these transition areas, the lingering presence of residual herbicides may further limit plant growth, favoring the most aggressive and often undesirable species. It is likely, given our interview results, that even under the best conditions, with the application of soil amendments, use of an optimum plant mix, and the availability of water provided by road surfaces, some type of vegetation management at the edge of the pavement will always be required. The interview results also suggested that it may be valuable to look at local native or at least non-invasive plant communities for selecting appropriate plant species.

We learned that no state included in our study has yet found a mix of purely native plants that works in Zone 1. However, Montana is fairly confident that its mix of non-native annuals and bi-annuals is helping it to establish natives along the roadside (it

seeds with mostly native grasses). It has been applying topsoil and seeding to the edge of the pavement after construction for several years. Idaho is another state that has made an effort to re-vegetate roadsides with natives and non-natives. California has a study under way to look at species selection and planting techniques for establishing native grasses along the roadside. New York is studying a mix of low-growing plants for areas under guardrails, but it is not emphasizing the need for natives in that situation.

Best Alternative Practices

One of the patterns we perceived in the interviews is that many states have tried experiments with alternative vegetation management approaches. Some have concluded that while there were some successes from those experiments, most of those experiments either didn't work or introduced substantial costs or new contaminants. Many are just beginning experiments with new approaches, and the results are too early to tell. We also found that most of the states involved in our interviews continue to use herbicides, at least in select locations for Zone 1 maintenance or for spot spraying to control invasive weed species. Some states do not use herbicides for the maintenance of a Zone 1 and have turned to mowing as their primary management tool. In addition, our interviews suggested that the timing of mowing is an important consideration in establishing a desirable plant community.

INTERVIEWS WITH OTHER GOVERNMENT AGENCY STAFF

The most significant issue in the management of roadside vegetation cited by non-transportation-related government agency staff was the environmental and health affects of herbicides, known and unknown. An environmental toxicologist at the U.S. Fish and Wildlife Service advised that there is evidence of sub-lethal effects from exposure to

some herbicides on endangered species. Also, the effects of herbicides used in combination or the inert ingredients in herbicides are frequently unknown.

In the absence of this knowledge, the current Health and Safety Inspector for King County's Environmental Health Department recommended in our interview with her that transportation agencies should consider adopting an approach that minimizes herbicide applications. She suggested an approach that begins with the lowest recommended application rate and works down to even lower rates to find minimum effective application rates. The North Cascade National Park is currently experimenting with the Wai Puna hot steam system to address noxious weed problems within the park. This system may be applicable for maintenance of Zone 1 without the use of herbicides. A pesticide expert at the U.S. EPA recommended that, at the policy level, transportation agencies should have site-specific limitations for individual herbicides based on localized environmental conditions because a state-wide management formula may not be sensitive to local issues. Flexibility in management formulas and community engagement at the local level may be more beneficial. This is consistent with WSDOT's current work to develop and implement locally based, site specific roadside management plans.

INTERVIEWS WITH CONSULTANTS

We spoke with professionals practicing in the areas of soil science and integrated vegetation management. Soil conditions surfaced as a significant issue for roadside plantings. This is of particular concern in relation to vegetation at the edge of pavement, where "soils" are typically composed of crushed rock. A consultant from Soil Dynamics, Inc., of Washington suggested that healthy soil is the key to establishing stable native plant communities because weed communities often thrive in soils with unbalanced

nutrients. Mechanical, biological and chemical properties of soils are interconnected and can all be adjusted by using various techniques. In sum, it is clear that establishing and maintaining vegetation on road shoulders need to include soil management strategies.

The implementation of a truly integrated vegetation management regime was a second salient issue that surfaced in our interviews. A consultant from IVM Partners in Pennsylvania noted that most transportation agencies and utilities spray broadly but should, instead, spray selectively to encourage desired plant communities rather than merely fight unwanted vegetation. The consultant also advocated the use of geographic information systems (GIS) mapping as a vegetation management tool. According to WSDOT maintenance staff, WSDOT is well on its way to utilization of a truly integrated and site-specific management process with the development of locally based roadside vegetation management plans that include site- and species-specific prescriptions for addressing vegetation management issues. These plans also include a geographic inventory of roadside vegetation management features along with the ability to generate maps as management tools.

INTERVIEWS OF UNIVERSITY RESEARCHERS

We spoke with researchers at selected universities that were involved with vegetation management, plant selection, and soil issues with respect to the roadside environment. Little to no research is being done on vegetation management in the most intensely impacted area immediately adjacent to the roadside. However, researchers at UC-Davis have looked at alternative 'organic' herbicides in comparison to conventional herbicides with limited success. They have also looked at species selection and soil preparation for native roadside plantings. It is too early, however, to report results. UC-

Davis has recently formed a roadside ecology research group that is likely to produce results that would be relevant to Western Washington.

CHAPTER 4
DECISION FRAMEWORK

BACKGROUND AND SCOPE

Decision Framework Context

WSDOT has traditionally used herbicides along with mechanical means, such as grading, to maintain a vegetation-free strip at the edge of the highway pavement on most highway segments statewide. This vegetation-free strip is referred to by WSDOT as Zone 1. Some citizens are concerned with this type of herbicide use because of the possibility of impacts on human health and the environment. Historically, over half of WSDOT's herbicide use has been dedicated to maintaining a vegetation-free condition in a strip 2 to 4 feet wide directly adjacent to the pavement edge. The reasons for this practice include, but are not limited to, pavement preservation, stormwater drainage, cost-effective maintenance, safety related to maintenance operation and highway users, and reduction of the potential for roadside fire starts.

There are alternatives to the conventional maintenance of Zone 1, but they have not been fully evaluated in terms of relative safety, cost-effectiveness, environmental impacts, and other aspects of highway design, operations, and maintenance. WSDOT personnel have begun experimenting with alternatives, have conducted some research on practices in other states and on county roads, and have developed a preliminary cost analysis of Zone 1 maintenance versus a vegetated shoulder approach. However, a more comprehensive assessment was needed to examine decision factors and alternative vegetation elimination or control options and to provide WSDOT with guidance for

specifying strategies and programming additional research. This project is serving this purpose; and the Decision Framework is envisioned as a means to organize and implement the project's results, as well as the findings of any subsequent research on this topic.

In its initial form the Decision Framework has many gaps in terms of the details of decision factors and vegetation elimination or control alternatives. Nevertheless, it will be a useful device even at the present state of knowledge to assimilate the results to date and to reveal alternatives ready for use in appropriate situations versus those requiring further investigation or not worth pursuing. The framework can be filled in, expanded, and adapted as additional knowledge accumulates.

The Decision Framework aims primarily at guiding pavement edge vegetation elimination or control along existing state highways. For new or reconstructed roads WSDOT will follow, to the extent possible, the principle of avoiding the need for maintenance of a Zone 1 through design innovations pursuant to the Department's recent Value Engineering (VE) initiative on this subject. A VE analysis and subsequent set of recommendations for design and construction is proceeding simultaneously with this project and its potential successors. While they are separate, the two activities definitely have strong potential for interchange of ideas for mutual benefit. For example, this project may uncover alternatives that could be applied both to new designs and redesign of existing roads. The VE recommendations, too, could contribute ideas that provide solutions for maintenance over the life of the highway following construction.

Definitions

Pavement edge zone—A strip parallel to the roadway extending approximately 2 to 4 feet from the pavement. The term pavement edge zone refers to a location only; this location may or may not have vegetation. WSDOT refers to a pavement edge strip (a location) kept free of vegetation (a condition) as "Zone 1."

Vegetation elimination—Actively managing to maintain a condition devoid of vegetation.

Vegetation control—Any management that does not seek vegetation elimination. Management for vegetation control includes, but is not limited to, mowing, selective removal, selective planting, reshaping, grading, and monitoring with no particular action if unneeded.

Decision factor—A problem or issue in road operation and/or maintenance that contributes to the decision of whether vegetation elimination or control is required and, if so, what type and how much.

Drainage-related decision factors—Issues with any direct or indirect association with the flow of water from the highway and through the pavement edge zone. Issues of primary concern include accumulation of water on the highway and attendant safety risk, overly extended pooling of water on the shoulder or in the pavement edge zone, channelization and erosion when impeded water finds an escape path, and undesirable amounts of sedimentation anywhere in the right of way. A related factor is point source pollution and filtration of stormwater, which is handled as a separate decision factor labeled Stormwater Management. In some instances (generally, very narrow or no paved

shoulder combined with high groundwater table), pavement deterioration through subsurface water accumulation can also be an issue.

Note: In this analysis pavement deterioration is considered to be a surface drainage-related decision factor, whereas deterioration of structures caused by water accumulation is not. The distinction is made because pavement is ubiquitous, while other structures are present intermittently.

Conventional Zone 1 maintenance—Maintenance of a vegetation-free-ground condition with non-selective herbicides applied annually in a solid band to a strip of soil at the pavement edge. In Western Washington this application always includes post-emergent herbicides and can also include pre-emergent herbicides.

Alternative—Any vegetation elimination or vegetation control substitute for conventional Zone 1 maintenance.

Non-conventional herbicide—A naturally occurring, post-emergent, non-residual, or individually injected herbicide applied selectively or in combination with other non-herbicide methods.

Environmental sensitivity—Potentially elevated risk of negative effects to humans, crops, domestic animals, water supplies, and/or natural aquatic and terrestrial ecosystems associated with conventional Zone 1 maintenance.

Use of the Decision Framework in Integrated Vegetation Management (IVM) Planning

The Decision Framework applies to highway segments of the scale typically analyzed in WSDOT's vegetation management plans. Hence, the anticipated scale falls somewhere between the micro-level, as small as one one-hundredth of a milepost (50 feet), and the macro-level of multiple mileposts covering long segments of highway

shoulders. The principal target users are maintenance area managers. Managers will use the framework to plan and map out vegetation management strategies by milepost in Integrated Vegetation Management (IVM) plans for application by maintenance workers.

The Decision Framework considers the relative cost effectiveness of alternative vegetation elimination or control strategies, but not on an individual, case-by-case highway segment scale. Instead, questions of cost effectiveness will be determined on a broader policy scale for implementation in common circumstances throughout the Western Washington state highway system.

The Decision Framework is oriented, first, toward determining whether there is a need to maintain a Zone 1 in a given situation or location and, if not, toward determining appropriate measures for controlling vegetation in the pavement edge zone. If one or more decision factors require maintenance of Zone 1, the framework emphasizes identifying the most cost-effective, safe, and appropriate alternative for maintaining a vegetation-free strip. Conventional maintenance of Zone 1 with non-selective residual herbicides is practiced if no feasible alternative exists and the location is not identified as relatively environmentally sensitive. In the latter situation the conventional mode of application must be adjusted, and the types and amounts of herbicide used must be limited to the least amount required to accomplish the needed vegetation elimination or control. In addition, WSDOT is committed to continuing assessment of emerging alternatives and actively engaging in development of new alternatives. Conventional herbicide practices should be replaced when and where practical, safe, and cost-effective alternatives become available.

It is recognized that some time will be needed to implement and evaluate workable alternatives after their identification. How long that period will be is a function

of a number of variables, such as the scope of the vegetation elimination or control task, the nature of the alternative and its installation/implementation and maintenance costs, and the availability of funds and equipment to implement it. Questions of timing and interim actions should be the subject of continuing dialogue between WSDOT maintenance employees and members of the Project Working Group and Technical Advisory Committee established for this project, with the goal of achieving the fastest alternative implementation consistent with highway operational necessities.

The Decision Framework consists of three modules:

- Decision Factors Module—A procedure to determine whether maintenance of Zone 1 is required in relation to nine decision factors and, if it is not required, what (if any) vegetation control should be considered.
- Alternatives Assessment Module—A procedure to assess the applicability of alternatives to conventional maintenance of Zone 1 according to the requirements identified in the Decision Factors Module.
- Environmental Sensitivity Analysis Module—A set of criteria to identify locations of relatively high environmental sensitivity, where the greatest effort should be put into finding workable alternatives to conventional Zone 1 maintenance.

The general procedure for using the framework is as follows (see Figure 4-1 for flowchart):

- Work through the Decision Factors Module to determine whether one or more decision factors require maintenance of Zone 1 or control of the vegetation type or quantity in the pavement edge zone.

- If maintenance of Zone 1 is required, go to Alternatives Assessment Module A. If vegetation control is required, go to Alternatives Assessment Module B. Identify the potentially feasible alternatives to conventional herbicide-based maintenance. Assess the identified alternatives with respect to effectiveness, affordability within the available budget, effects on highway operations, and environmental impacts (including but not limited to toxicity to humans and other species, erosion, water pollution, and air pollution).
- Implement the most cost-effective, safe, and least environmentally harmful available alternative.
- If no alternative is available or if all available alternatives are unaffordable or have unacceptable side effects, go to the Environmental Sensitivity Analysis Module to determine the relative environmental sensitivity of the location in question to conventional maintenance of Zone 1 with non-selective herbicides.
- If the location is relatively environmentally sensitive, proactively identify, develop, and test new alternatives. Go to the Alternatives Assessment Module and reassess the alternative management strategies.
- If the location is not relatively sensitive, specify the most limited and controlled and least toxic conventional non-selective herbicide application while continuing to assess emerging alternatives and proactively identify, develop, and test new alternatives. Go to the Alternatives Assessment Module and reassess the alternative management strategies.

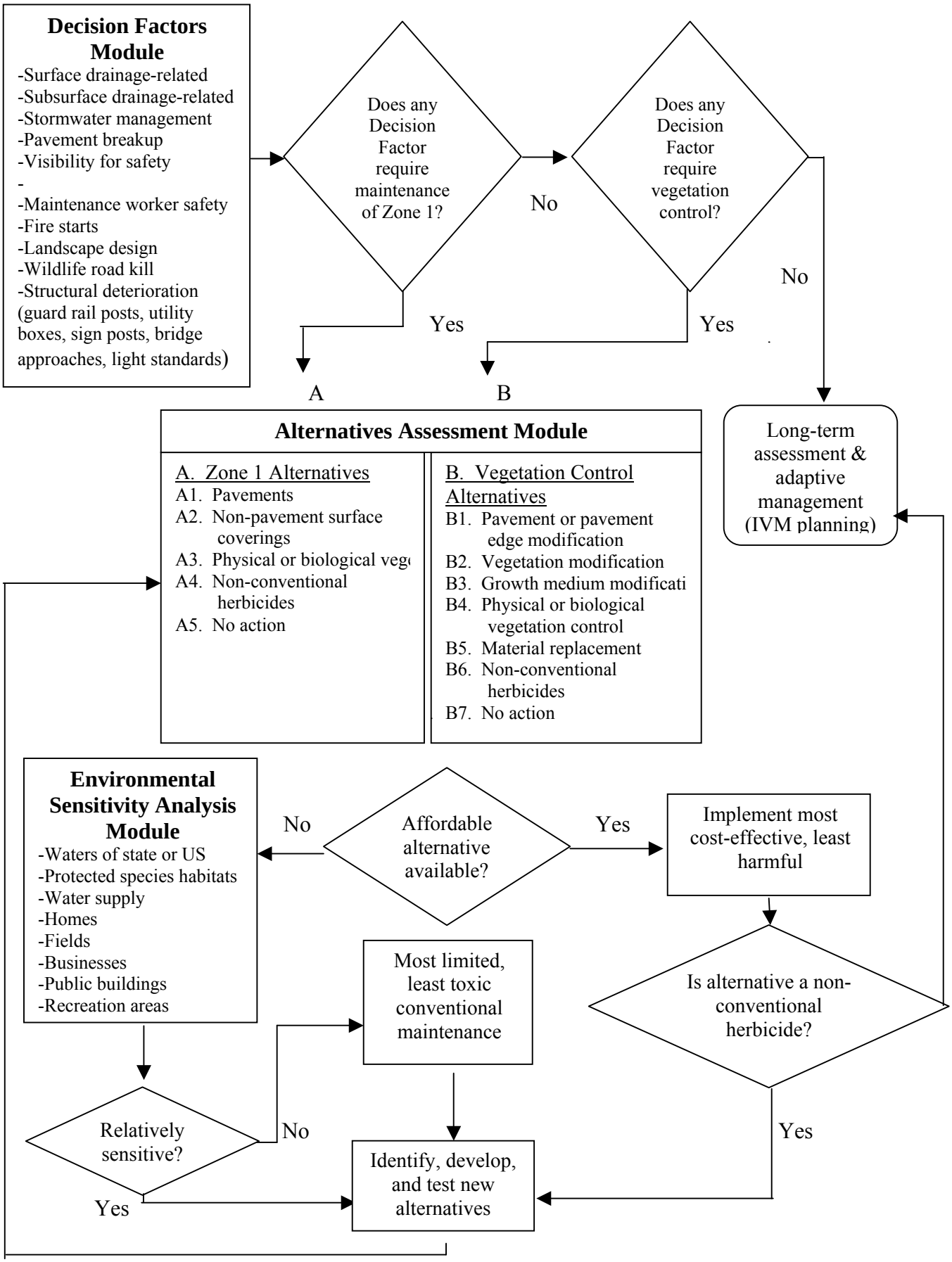

Figure 4-1. Flowchart diagram for decision framework.

- If the only feasible alternative is a conventional, non-selective herbicide, assess the emerging alternatives and proactively identify, develop, and test new alternatives. Go to the Alternatives Assessment Module and reassess the alternative management strategies.
- Reassess decisions periodically over the long term and adapt management strategies according to the outcome through integrated vegetation management (IVM) planning.

MODULES

Decision Factors Module

General Procedure

- Consider the first decision factor to determine whether maintenance of Zone 1 is required.
- If maintenance of Zone 1 is not required, consider the next decision factor and make the same determination. If maintenance of Zone 1 is again not required, go on to the following decision factor, and then the following one, and so on.
- In the case of any decision factor for which maintenance of Zone 1 is required, go the Alternatives Assessment Module.

Surface Drainage-Related Decision Factor

Maintenance of Zone 1 is not required if:

- The pavement edge zone cannot receive highway drainage, such as where:
  - Roadway configuration (e.g., superelevation) directs all drainage from the hydrologic design precipitation event to the opposite side of the road.

- A curb or formal or informal drainage channel between the pavement and pavement edge zone conveys runoff away from vegetation.
- The shoulder pavement edge angles and extends downward along the shoulder slope (i.e., Zone 1 is, in effect, paved).

Or

- The pavement edge zone does receive drainage, but the absence of conventional Zone 1 maintenance does not interfere with the other factors listed below. Case in point: Routine blading for snow removal covers the intersection of the pavement and the pavement edge zone.

Or

- There is at least a minimal vertical recess from the pavement to the pavement edge vegetated surface, and the pavement edge zone slopes at a gradient of at least 2 percent away from the pavement on elevated and fill roadway segments.

Subsurface Drainage-Related Decision Factor

Maintenance of Zone 1 is not required if:

- The roadway has a paved shoulder of at least the standard width for the highway category.

Or

- The seasonal high water table is at least 3 ft below the traveled lane grade.

Stormwater Management Decision Factor

Note: This decision factor concerns using vegetation adjacent to the pavement edge zone as a filter strip to remove pollutants from stormwater runoff. It is essential that flow onto a filter strip be evenly distributed in sheet flow along its width (dimension

perpendicular to flow) and not be concentrated. Adequate vertical drop from the pavement to the vegetation, slope, or a combination of both are likely to be sufficient for this purpose. Otherwise, a narrow flow spreader without vegetation, typically gravel, is recommended. If a flow spreader is necessary, some means is generally necessary to exclude flow-restricting vegetation. In new construction a geotextile can be installed. Other means of vegetation elimination may be necessary when an existing slope is converted to a filter strip.

Maintenance of Zone 1 is not required in relation to stormwater management if:

- It is not required according to the criteria for the Surface Drainage-Related Decision Factor.

Pavement Breakup Decision Factor

Note: This decision factor concerns pavement deterioration through direct intrusion by vegetation.

Maintenance of Zone 1 is not required in relation to stormwater management if:

- The pavement type is known not to be prone to vegetation intrusion.

Or

- Vegetation species known to intrude into and deteriorate pavement are not present in the right of way or adjacent areas.

Or

- If one or more of these species are present, intrusion into pavement has not been observed over at least a two-year period.

Visibility for Safety Decision Factor

Maintenance of Zone 1 is not required if:

- The roadway segment is straight for a distance of at least "x."

Note: There may be situations where the distance is less than "x" but greater than "y" that would not require complete vegetation elimination but some control of the vegetation type and/or quantity.

Or

- A curved roadway segment has a radius of curvature of at least "x."

  Note: There may be situations where the radius is less than "x" but greater than "y" that would not require complete vegetation elimination but some control of the vegetation height, type, and/or quantity.

Or

- Vehicles do not enter the travel lane from an intersecting road.

  Note: There may be situations that would not require complete vegetation elimination but some control of the vegetation height, type, and/or quantity.

  (*Safe vehicle recovery does not have any relation to Zone 1 maintenance*)

Maintenance Worker Safety Decision Factor

Maintenance of Zone 1 is not required if:

- The pavement edge zone is behind a guard rail or other barrier.

Or

- Workers can be adequately protected for any activities needed to manage the type and/or quantity of vegetation by wide-paved shoulders, by a shoulder or lane closure, or through the use of equipment that does not directly expose them to traffic.

Fire Starts Decision Factor

Maintenance of Zone 1 to prevent fire starts by vehicles is not required if:

- The pavement edge zone starts a distance of at least “x” away from the travel lane.

Or

- Topography or a guard rail or other barrier would prevent a burning vehicle from driving onto the pavement edge zone.

Or

- A sufficient paved shoulder exists to park a burning vehicle.

Maintenance of Zone 1 to prevent fire starts by burning material is not required if:

- The pavement edge zone starts a distance of at least 20 ft away from a paved surface. (According to results presented in the California Division of Forestry’s Fire Hazard Reduction Guide for Roadsides, this spacing would cut the fire risk to under 15 percent; refer to the project literature review.)

Or

- The pavement edge zone starts a distance of at least “y” ($y < 20$ ft) away from a rough surface (e.g., gravel).

Or

- The vegetation present is not expected to be flammable in the driest period of the year if contacted by burning material.

Landscape Design Decision Factor

Maintenance of Zone 1 is not required if:

- The vegetation conforms to the criteria established for the location's landscape design.

Or

- The vegetation does not conform to the criteria but there has been no negative public reaction on aesthetic grounds.

Wildlife Road Kill Decision Factor

Maintenance of Zone 1 is not required if:

- The road segment is in an area with little nearby habitat that would house or attract animals.

Or

- Road maintenance forces report a history of few road kills in the area.

Structural Deterioration Decision Factor

Maintenance of Zone 1 is not required if:

- There are no guard rails, utility boxes, sign posts, bridge approaches, or light standards.

Or

- Structural materials are not subject to deterioration caused by the presence of vegetation.

  Note: Where these conditions do not exist, there may be situations where structural integrity can be ensured without complete vegetation elimination but some control of the vegetation type and/or quantity.

Noxious Weed Presence

Noxious weed presence was originally considered as a decision factor but was eliminated from the Decision Framework because this factor is already being handled under WSDOT's Integrated Vegetation Management program.

Alternatives Assessment Module

Assess the applicability of alternatives to conventional non-selective herbicide usage to accomplish the required vegetation elimination according to the stated criteria. If maintenance of Zone 1 is needed, consider alternatives for maintaining a non-vegetated condition. If vegetation need not be eliminated but must be controlled in some way, consider alternatives for controlling vegetation. Follow the application guidance where available for the selected alternative. Assess the identified alternatives with respect to effectiveness, affordability within the available budget, effects on highway operations, and environmental impacts (including but not limited to toxicity to humans and other species, erosion, water pollution, and air pollution).

The Decision Framework is comprehensive in listing the alternatives that have been mentioned by the literature and interviewees consulted during this project. However, application details have not been worked out for many of the alternatives that have come up. These alternatives are candidates for future research. Application guidelines are given below where available. If no or insufficiently specific guidance is available now, the place reserved for application guidelines is left blank. For certain entries where some guidance is given, it is sketchy at present and must be upgraded as the field develops.

A. Alternatives for Maintenance of Zone 1

Group A1. Pavement alternatives—Extending or installing paving material in the pavement edge zone either over a length of highway or in the vicinity of structures.

Important note: Pavement directly abutting a guardrail or sign post impedes rigid-body rotation and deformation of the post. Because the energy-absorbing capability of a post relies on its ability to rotate, there must be a gap of 8 inches between pavement and post. To limit vegetation around posts use flexible collars or non-rigid treatments such as grout-filled leave-outs.

A1a. Modified pavement-edge design—Extending the shoulder pavement into the pavement edge zone.

Application guidelines: The roadside edge must be structurally stable with soil compacted as necessary to support pavement.

A1b. Porous pavement—Coarse-graded asphalt or concrete that permits water penetration and infiltration into underlying soil. The following information was assembled for and presented by the Infiltration Facilities for Stormwater Quality Control Workshop Manual, prepared for the Managing Stormwater Runoff Workshop, Milwaukee, Wis., June 9, 1999, by R.R. Horner.

Application guidelines: Porous asphalt suitable for a road with substantial traffic consists of a porous asphalt top course, a filter course, a reservoir course, and filter fabric. The top course is an asphalt paving mixture with all the structural properties of conventional asphalt, but it uses an aggregate mix in which fine particles are kept to a minimum. A simpler design could be used for non-roadway applications. For example, a porous asphalt shoulder was tested for water quantity and quality control along a King County road. It had only a 3.5-inch deep porous asphalt course over natural soil to be approximately equivalent in cost to

conventional asphalt and gravel shoulders. It performed well in stormwater control and did not clog through one winter of use plus extra sanding loading equivalent to four more winters. Typical porous asphalt specifications are as follows:

- Aggregate: A number of aggregate mixes have been used in porous asphalt pavements. The best choice from the infiltration standpoint is a mix with the lowest proportion of particles passing the No, 200 sieve, although at least 2 percent in that fraction seems to be needed for stability.
- Asphalt content and void volume: Asphalt content should be 5.5 to 6.0 percent. Void volume is generally > 20 percent, compared to 2 to 3 percent for conventional asphalt.
- Porous asphalt course thickness: 2.5 to 6.0 inches, depending on traffic loads.
- Filter course: 0.5-inch crushed stone 2 inches thick.
- Reservoir course: 1 to 2 inch crushed stone; thickness based on required storage.

The porous concrete is structurally simpler than the asphalt section and is generally placed directly on the soil. Without a reservoir course, the soil must be capable of infiltrating water fast enough to prevent surface runoff for the design condition. Pervious concrete contains a relatively large proportion of aggregate larger than the No. 4 sieve opening.

<u>A1c. Asphalt Concrete (AC) Pavement</u>— Asphalt concrete mixed, spread, and compacted according to prevailing standards.

Application guidelines: The base material (4 to 8 inches) and AC depth (2 to 6 inches) will vary depending on site-specific requirements. Because it is a rigid material, no AC is allowed within 8 inches of guardrail and sign posts. To limit vegetation around posts, use flexible collars or non-rigid treatments. More information, including benefits, limitation, and costs, is available at http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.

A1d. Aggregate— Placing a compactable traffic-bearing material, such as standard aggregate base or pavement milling mulch, and compacting the material (90 to 95 percent) to prohibit root growth.

Application guidelines: The base material should be free of organic matter and other deleterious substances that would support vegetation. For this application materials should not be composed of recycled asphalt or cement based materials as allowed for road base in the standard specifications. Use only in areas with good access for performing re-compaction on a regular basis (i.e., not under guardrail and similarly constricted spaces). Incorporating a stabilizing polymer into the mix prior to compaction may extend the life cycle of the treatment. More information, including benefits, limitation, and costs, is available at http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.

A1e. Asphalt-treated base—Aggregate base with the addition of asphalt.

Application guidelines: (None available currently.)

Group A2. Non-pavement surface covering alternatives—Materials other than pavements intended to prevent vegetation growth.

A2a. Weed control mat (fiber)—Synthetic polyester fibers spun together to create a mat that prevents weed growth by inhibiting sunlight penetration while allowing for water and air percolation.

Application guidelines: Fiber weed control mats are best suited for areas with long straight runs of guardrail or signpost installations. The treatment is not easily applied to curves. Fiber barriers are most effective on level, compacted bases that are free of vegetation. Attach to soil as directed by the manufacturer. Collars must be sealed around posts to prevent weed growth. Use of fabric barriers in high wind areas is not recommended. More information, including benefits, limitation, and costs, is available at http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.

A2b. Weed control mat (rubber)—Adopted technology used primarily for playground safety surfacing. Tiles prevent sunlight from reaching the ground surface, retarding seed germination and plant growth. The major component is recycled tire rubber bonded together with a resin into a mat.

Application guidelines: Use under guardrail and fences and around sign posts. Rubber mats are not recommended for large, non-linear areas or slopes. Preferred placement is with "Krafco-type" machine for joint sealing. Cut outs are molded or cut into the tile for post placement. The inherent weight of the tiles keep them in place, no staking is usually required. Mats are joined together with an overlap that is sealed with an asphalt crack filler or resin adhesive. More information, including benefits, limitation, and costs, is available at

http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.

A2c. Polyureas—Polyureas, or elastomers, are derived from a combination of isocyanate and resin blend components. Typically, the product is applied through a spray, with the two components combined at the nozzle. The result is a hard but semi-flexible product, similar to a truck bed liner, that cures quickly (less than 1 minute).

Application guidelines: Use primarily under existing guardrails and around sign posts, where a spray-on application has the greatest benefit. Apply in relatively thin coats over a geotextile fabric stapled to the ground surface. Installation requires a well prepared, compacted, and smooth surface to limit pockets. Ensure that the area to be treated has positive drainage. More information, including benefits, limitation, and costs, is available at http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.

A2d. Turboscape—Recycled tire material and adhesive blown by hose; can be pervious or impervious depending on thickness.

Application guidelines: Turboscape is principally intended for guardrail applications.

Group A3. Physical or biological vegetation control alternatives—

A3a. Hot water, steam, and foam—Sprayed application that kills the tops of non-woody plants but has unknown effects on the roots and seed banks.

Application guidelines: The Wai Puna hot steam system, a sucrose mixture in water, has being used by the National Park Service at 209 degrees Fahrenheit. Multiple applications are needed.

A3b. Radiant heat—Infrared radiation application.

Application guidelines: Infrared is more effective on relatively low-growing (2 inches or less) and lightly covering vegetation than on taller, denser growths. Apply three to four times a year in the former situation and eight times or more, if used at all, on relatively dense growth. Mow tall plants first. Avoid or use with extreme caution in the fire season, and obtain fire permits as required. More information is available in the report by Edgar (2000); refer to the project literature review.

A3c. Controlled burning—Purposely set fire.

Application guidelines: This alternative has potential air quality impacts that must be assessed in conjunction with any use under consideration.

A3d. Salt water—Spray of water with seawater salinity.

Application guidelines: Must be near a salt water body or where there is otherwise a large supply of salt. Salt application can salinize the soil to the extent that Zone 1 cannot be converted to a vegetated area without removing the soil and bringing in replacement soil.

A3e. Mild acids—Generally vinegar or acetic acid spray.

Application guidelines: A 15 to 20 percent vinegar solution is needed to achieve a high kill rate on mature plants. In early stages a 5 to 10 percent solution suffices. Because vinegar changes soil pH, a lighter application is preferred if adequate. In any case the soil may have to be limed to moderate pH if Zone 1 is converted to a vegetated strip. More information is available in the report by Radhakrishnan et al. (2002); refer to the project literature review.

A3f. Time-specific policies—Scheduling application of physical or biological vegetation control or non-conventional herbicide for the greatest effect with the least negative impact.

Application guidelines: In general, if a treatment has potential negative impacts, apply it at the lowest effective rate at first and increase only if necessary. Specific guidelines are given for some alternatives.

A3g. Site-specific policies—Tailoring the application of physical or biological vegetation control or non-conventional herbicide to site-specific conditions instead of following general regional policies or policies based on plant species.

Application guidelines: (None available currently.)

A3h. Targeting maintenance with smart technologies—Emerging options include electronic targeting systems, GPS, pattern recognition, flexible application devices, and visioning systems that spot vegetation to be treated.

Application guidelines: (None available currently.)

Group A4. Non-conventional herbicide alternatives—A naturally occurring, post-emergent, non-residual, or individually injected herbicide applied selectively.

A4a. Organic herbicides—Emerging options include crop oils, corn gluten, pine oil, and plant essences.

Application guidelines: (None available currently.)

A4b. Post-emergent herbicides—Herbicides selectively applied after vegetation has partially developed.

Application guidelines: (None available currently.)

A4c. Non-residual herbicides—Herbicides that rapidly decompose and have no significant ongoing action or presence.

Application guidelines: (None available currently.)

A4d. Individually injected herbicides—Herbicides applied plant by plant.

Application guidelines: (None available currently.)

A2e. Herbicidal fabric (with gravel cover)—Herbicidal geofabrics are similar to a synthetic landscape fabrics with a time-released, pre-emergent herbicide impregnated in the fabric or in nodules connected to the fabric. The herbicide restricts the growth of new roots, impeding the ability of the plant to spread and grow.

Application guidelines: Do not place near water courses. Fabric must have a cover material to prevent movement and improve aesthetics, with gravel recommended. This treatment may be used in combination with other treatments such as mulches or inert cover materials around signposts and guardrails. More information, including benefits, limitation, and costs, is available at http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.

Group A5. No action alternative—Applying no treatment to maintain Zone 1 but still monitoring and managing adaptively if monitoring results suggest a change in strategy.

A5a. No action—Applying no treatment to maintain Zone 1 but still monitoring and managing adaptively if monitoring results suggest a change in strategy.

Application guidelines: (None available currently.)

B. Alternatives for Vegetation Control

Group B1. Pavement or pavement edge modification alternatives—

B1a. Slope modification—Altering a slope with little or no gradient to ensure that runoff flows away from the road.

Application guidelines: Create at least a minimal vertical recess from the pavement to the pavement edge vegetated surface, and slope the pavement edge zone at a gradient of at least 2 percent away from the pavement surface cross-grade.

B1b. Curbing—Preventing the flow of runoff onto the pavement edge zone by installing a curb.

Application guidelines: This strategy is contrary to the objective of retaining runoff in sheet flow for treatment by vegetation, which should be carefully considered before selection.

Group B2. Vegetation modification alternatives—Replacing vegetation creating problems identified in the Decision Factors Module with plants that will avoid those problems.

B2a. Modifying vegetation selection—Establishing vegetation, often native plants, that can avoid problems identified in the Decision Factors Module and that is largely self-sustaining

Application guidelines: The report "Planting for Sustainable Roadsides: Empirical and Experimental Studies and Recommendations for Western Washington" by Hamilton et al. (1998) covers the subject in detail (refer to the project literature review). In particular, Chapter 5 lists native bunchgrasses and other native plants recommended for roadsides. The

chapter also gives ten recommendations to advance the success of these plants.

B2b. Replacement of conventional roadside vegetation with moss—Propagating a completely covering moss stand to discourage spermatophytic plant growth.

Application guidelines: (None available currently.)

Group B3. Growth medium modification alternatives—Biologically, chemically, and/or physically altering the soil.

B3a. Adjusting soil biology—Introducing organisms beneficial to the growth of desired vegetation.

Application guidelines: (None available currently.)

B3b. Adjusting soil chemistry—Fertilizing to adjust the nutritional balance favorable to the growth of desired vegetation.

Application guidelines: (None available currently.)

B3c. Soil binders—A material that helps create an open soil structure that readily admits air and water.

Application guidelines: Gypsum (calcium sulfate) helps prevent crust formation.

B3d. Compost—Well decomposed carbonaceous material mixed into the soil and intended to increase the organic content for better structure, water-holding ability, and nutrition.

Application guidelines: Typical specifications are: moisture content—30 to 60 percent; bulk density—700 to 1200 lbs/cubic yard; pH—5.5 to 8.0; organic content—35 to 55 percent; carbon nitrogen ratio—10 to 20:1;

inerts—a < 1 percent; particle size—0.5 to 1.0 inch; and heavy metal content meeting EPA 503 regulations. With compost that has more than 50 percent organic content derived from municipal solid waste, apply 10 to 15 tons/acre (15 tons/acre ≈ 0.25 inch thickness) to mineral soils to increase water holding capacity by 5 to 10 percent. Apply more than 15 tons/acre to increase organic content substantially. Compost addition may alter pH, especially in acid soils at 10 to 20 tons/acre, requiring lime addition. More information is available in the report by Kirchhoff et al. (2002); refer to the project literature review.

B3e. Mulch—Organic ground cover intended to create a barrier to weed growth.

Application guidelines: (None available currently.)

B3f. Highway sweepings—Material recovered from highway sweepers to mix in the soil to improve organic content.

Application guidelines: (None available currently.)

B3g. Topsoil—Imported material to improve the upper soil horizon.

Application guidelines: (None available currently.)

B3h. Topsoil with geo-grid—Heavy-duty plastic cellular network, which stabilizes soil and supports occasional light traffic but allows vegetation to grow through, installed in topsoil.

Application guidelines: (None available currently.)

Group B4. Physical or biological vegetation control alternatives—Mechanical and biological procedures to reduce live plant biomass.

B4a. Mowing (includes machine and hand procedures)—Cutting with riding or motorized hand equipment.

Application guidelines: According to Stewart (1986; refer to project literature review), the best time to control broadleaf and woody plants is in the late spring or summer, just after new growth finishes developing, and tissue is green and soft. For other vegetation, cut off shoot growth before it starts to send food into roots and flowers. Another cutting may be needed later.

B4b. Hand removal—Pulling without the use of motorized equipment.

Application guidelines: Primarily for removal of relatively isolated noxious weed growths.

B4c. Blading, grading—Scraping the pavement edge zone to adjust the soil height and slope as well as remove vegetation.

Application guidelines: Effective drainage from the roadway is enhanced by creating at least a minimal vertical recess from the pavement to the pavement edge vegetated surface, and by sloping the pavement edge zone away from the road. A gradient of at least 2 percent is preferred if possible.

B4d. Cultivation, tilling—Breaking the soil with a plow, fork, disk, or harrowc. to reduce compaction and improve air and water penetration before attempting to establish desirable growth; also disrupts unwanted plants.

Application guidelines: According to the Montana Department of Transportation (2003) Statewide Integrated Weed Management Plan,

2003-2008 (refer to the project literature review), tilling is effective against annuals and tap-rooted perennials. The best control occurs when the soil is dry, so that plant fragments lack moisture to regrow. Combine tilling with reseeding of desirable species, mulching, and perhaps composting or other soil-building measures if needed.

B4e. Preventive maintenance—Early removal of small growths of undesirable vegetation before spreading occurs.

Application guidelines: (None available currently.)

B4f. Vegetation control by livestock—Plant removal or height control by grazers.

Application guidelines: (None available currently.)

B4g. Vegetation control by insects—Introducing a predator able to control the target plant species without attacking desired vegetation.

Application guidelines: An insect is introduced from the region where the target weed originated. Because of the high risk to non-target species, using this technique requires an extensive testing program and final approval by the U.S. Department of Agriculture.

B4h. Vegetation growth regulators—Application of a biochemical responsible for the growth of the target species but not non-target organisms.

Application guidelines: (None available currently.)

B4i. Time-specific policies—Scheduling the application of physical or biological vegetation control or a non-conventional herbicide for the greatest effect with the least negative impact.

Application guidelines: In general, if a treatment has potential negative impacts, apply it at the lowest effective rate at first and increase only if necessary. Specific guidelines are given for some alternatives.

B4j. Site-specific policies—Tailoring the application of physical or biological vegetation control or a non-conventional herbicide to site-specific conditions instead of following general regional policies or policies based on plant species.

Application guidelines: (None available currently.)

B4k. Targeting maintenance with smart technologies—Emerging options include electronic targeting systems, GPS, pattern recognition, flexible application devices, and visioning systems that spot vegetation to be treated.

Application guidelines: (None available currently.)

Group B5. Material replacement alternatives—Changing from a material harmed by vegetation contact to one not so affected.

B5a. Use of metal posts—Conversion of wood guardrail and sign posts to metal.

Application guidelines: (None available currently.)

Group B6. Non-conventional herbicide alternatives—A naturally occurring, post-emergent, non-residual, or individually injected herbicide applied selectively.

B6a. Organic herbicides—Emerging options include crop oils, corn gluten, pine oil, and plant essences.

Application guidelines: (None available currently.)

B6b. Post-emergent herbicides—Herbicides selectively applied after vegetation has partially developed.

Application guidelines: (None available currently.)

B6c. Non-residual herbicides—Herbicides that rapidly decompose and have no significant ongoing action or presence.

Application guidelines: (None available currently.)

B6d. Individually injected herbicides—Herbicides applied plant by plant.

Application guidelines: (None available currently.)

Group B7. No action alternative—Applying no treatment to control vegetation but still monitoring and managing adaptively if monitoring results suggest a change in strategy.

B7a. No action—Applying no treatment to control vegetation but still monitoring and managing adaptively if monitoring results suggest a change in strategy.

Application guidelines: (None available currently.)

Environmental Sensitivity Analysis Module

The location is considered to be environmentally sensitive to conventional non-selective herbicide application if it is:

- Within "x" distance of any waters of the state or U.S. or tributaries to them.

Or

- Within legally specified distances (exclusive of label requirements) from waters or terrestrial habitatshousing protected rare, threatened, or endangered species on regulatory lists.

Or

- Within “x” distance of an individual or public water supply (surface or subsurface).

Or

- Within "x" distance of homes;

Or

- Within "x" distance of gardens and farm fields.

Or

- Within "x" distance of businesses.

Or

- Within "x" distance of public buildings.

Or

- Within "x" distance of outdoor public recreation areas.

CHAPTER 5
FURTHER WORK

VEGETATION MANAGEMENT PLANS

WSDOT staff are preparing a Vegetation Management Plan for each county or maintenance sub-area in the state. Seven of these have been completed to date, including Vegetation Management Plans for Island County, Clallam and Jefferson counties, and Bainbridge Island. (The full set of plans can be found at http:// wsdot.wa.gov/maintenance/vegetation). The intent of these Vegetation Management Plans is "…to achieve the best and most consistent roadside maintenance practices throughout the corridors and to maximize the efficiency and effectiveness of maintenance program delivery over time. Success in meeting this goal will be measured by the improvement of the overall health of the roadside, a resulting minimization of roadside maintenance costs, and a corresponding minimization of herbicide use over time." (Whidbey Island Roadside Vegetation Management Plan, WSDOT, 2005, p. 2).

OBSERVING PROBLEM AREAS

In order to continuously improve the efficiency and effectiveness of roadside maintenance programs, field staff will need to observe problem areas and record information about the conditions that occur there. For instance, areas where ponding occurs on the paved surface of roads may be associated with thick vegetation that blocks free drainage of stormwater. Alternatively, these may be places where the shoulder has been graded incorrectly, or where debris has accumulated from the rest of the roadway surface. Field staff will need to observe a number of conditions, including the density and

height of roadside vegetation, the grading of the shoulder, and the presence of debris, to determine the cause of the ponding.

A systematic approach to data collection and analysis is required, so that anecdotal information about particular cases does not become the sole basis for maintenance decisions. Systematic observations can often confirm casual observations, but they may also challenge the conclusions that are drawn from a few particular instances.

Several sample worksheets for recording observations about roadside vegetation maintenance problems are included in Appendix D, Part I. These include worksheets for recording observations related to stormwater ponding, fire starts, wildlife road kills, and debris accumulation.

EXPERIMENTAL FIELD TRIALS

In keeping with the development of Vegetation Management Plans and the Decision Framework presented in this report, WSDOT staff have identified opportunities to try new maintenance materials and techniques that seem to be particularly promising. The Vegetation Management Plans identify a number of experimental vegetation maintenance treatments that are to be used in particular locations within the area covered by the plan. This represents an ongoing effort by WSDOT maintenance staff to examine the effectiveness of new techniques by using experimental field trials.

Ideally, these field trials should be located on the basis of information from the Vegetation Management Plans and should be designed to produce answers to maintenance questions that are significant to WSDOT staff as they implement the Vegetation Management Plans. The first and most important of these questions must be

whether or not vegetation maintenance is required in the zone immediately adjacent to the pavement edge. The answer to this question may be specific to particular locations or conditions. If no problem occurs from an absence of frequent vegetation maintenance, then the most cost-effective and efficient solution may be that maintenance is deferred to annual or semi-annual treatments. Multi-year trials will be required to determine whether less-frequent maintenance is effective in preventing problems from occuring over time, and whether such maintenance is more cost effective than more frequent treatments.

Moreover, because one of the goals of the WSDOT vegetation maintenance program is to move to selective use of herbicides, these trials should also be designed in part to assist field staff in finding cost-effective alternatives to the use of pre-emergent herbicides. When problems are observed to occur that may require vegetation maintenance, such as frequent fire starts or ponding of stormwater runoff, cost-effective alternatives to herbicide use may be available. The only way for field staff to know whether these alternatives are more cost effective and efficient is to engage in field trials that have been designed to answer specific questions and that are observed systematically over time.

Part II of Appendix D in this report contains a sample sheet for recording field observations in experimental trial situations.

NEXT STEPS

Maintenance staff have already initiated a number of field trials. These may be observed by using the sample field trial observation sheets included with this report, modified as needed. Additional work should be done, however, to make sure that these

experiments are designed to answer questions that are important to strategic management decisions about the efficient use of resources.

First, a short-list of questions should be developed that reflects the priorities of WSDOT maintenance staff and managers. This list may include questions about the origin of particular maintenance problems, such as frequent fire starts. It may also include questions that compare particular methods of controlling vegetation where maintenance has been found to be necessary on the basis of cost effectiveness, worker safety, or other issue.

Second, the design developed for the experimental trials should attempt to account for influences on the site that are unrelated to the central question. For instance, south-facing slopes and north-facing slopes on roadsides may have different rates of plant growth. Or, roads with heavy logging truck traffic may be more likely to accumulate woody debris along the pavement edge than other roads. The sites for experimental trials should be selected with these variables in mind in order to either study them directly or minimize their influence on the study of other patterns.

Third, a systematic pattern of observation and data collection should be adopted that is time-efficient, yet allows staff to consistently record the key variables that are most important to the trial or study. The use of a standardized observation sheet is likely to be important for each trial, or at least for all trials of a certain type (studies of debris accumulation might all use the same data sheet, while studies of stormwater ponding would likely require a different data sheet).

Fourth, data must be analyzed in ways that allow WSDOT managers to answer the questions that prompted the study in the first place. In some studies, a fairly high level of accuracy may be required in the analysis of the data. In others, a qualitative ranking of

the relative success of different maintenance methods or ranking of the conditions at different sites may be sufficient. The nature of this final step must actually be determined in advance, as the study is being designed, so that the appropriate types of observations are made in the field. If the study has been designed appropriately, analysis of the field observations will be the final step that produces information that is of use to maintenance managers and supervisors of field staff.

The next steps in developing an Integrated Vegetation Management Program may require that (a) systematic observations be designed and undertaken to better understand roadside management problems that may or may not require vegetation maintenance, and (b) experimental field trials be designed, implemented, observed, and analyzed to determine whether cost-effective alternatives to standard WSDOT maintenance approaches are available.

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APPENDIX A
LITERATURE REFERENCES

SECTION I. ARTICLES IN PEER-REVIEWED JOURNALS, AND PEER-REVIEWED BOOKS

(NOTE: Abstracts were included for all references when they were available.)

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[Four herbicides, atrazine, simazine, paraquat, and glyphosate were tested for their acute and chronic toxicity as well as repellent effects on five common carabid beetles (Amara sp., Agonum sp., Pterostichus sp., Anisodactylus sp., and Harpalus sp.) in laboratory and greenhouse experiments. These carabid species are potential biocontrol agents and interference with their biology through herbicide applications, either directly or indirectly, could lead to soil pest outbreaks. Short-term field studies also were conducted to verify laboratory and greenhouse results. The four herbicides did not have significant acute or chronic effects on male or female carabid longevity or food consumption during one year after exposure to initial field-rate applications. Only simazine and atrazine had a repellent effect on carabids, which lasted approximately three days in greenhouse studies. Behavioral studies indicate that once carabids, especially smaller ones (< 10 mm in length), establish burrows and foraging territories, they tend to remain in these areas and migrate out of them only slowly. There was no toxic or repellent effect of any herbicide in the field. Carabids, instead, apparently responded to the destruction of plant material which provided a less favorable habitat for the larger (> 10 mm length) carabids. Glyphosate and paraquat had the greatest effect on carabids by the second week in field studies, with significantly fewer large carabids found in these two treatments than in the control. Large carabids did not return to paraquat- and glyphosate-treated field areas until approximately 28 days after application; consequently, lower rates of predation of early-season lepidopteran pests by these carabid species may occur in no-tillage corn fields that utilize herbicides for weed control.]

Busse, Kendra. "A native landscape for Interstate 15? A decision case in environmental science." ed. Allen, Phil, **Journal of Natural Resources and Life Sciences Education.** 2003. 32: 118-125.
[Between 1996 and 2001, the section of Interstate 15 (I-15) through Salt Lake City, UT, was redesigned, rebuilt, and expanded in preparation for the 2002 Winter Olympics. The aesthetic theme proposed for the freeway roadside was announced to be a natural

landscape consisting of native plants. Dr. John Atwood, a local scientist and plant expert, was hired to provide recommendations for plant selections and seed mixes. In the course of planning the roadside, a conflict surfaced regarding the desirability and feasibility of a "native plant landscape." Atwood's preliminary recommendations had been submitted for review by other scientists (plant breeders not associated with the freeway project) who were highly critical of native plants. The plant breeders argued that the only successful I-15 landscape would consist of exotic species selected for superior performance under Utah's harsh environmental conditions. An all-native roadside landscape had never before been attempted in Utah. Atwood's recommendations would influence the spending of millions of dollars, and the high visibility of the project meant that failure would seriously undermine his professional reputation. The decision whether to use native plants along I-15 illustrates the kind of real-life dilemma that can occur when attempting to resolve an environmental issue. The case was developed for use in environmental science, horticulture, ecology, range management, and landscape architecture courses, and can be used as a basis for discussions about challenges faced when decisions must be made in the absence of complete data and where experts disagree.]

Busse, Matt D., et al., eds. Ratcliff, Alice W.; Shestak, Carol J.; Powers, Robert F. “Glyphosate Toxicity and the Effects of Long-Term Vegetation Control on Soil Microbial Communities.” **Soil Biology and Biochemistry**. 2001. 33(12-13): 1777-1789.
[We assessed the direct and indirect effect of the herbicide glyphosate on soil microbial communities from ponderosa pine (Pinus ponderosa) plantations of varying site quality. Direct, toxic effects were tested using culture media and soil bioassays at glyphosate concentrations up to 100-fold greater than expected following a single field application. Indirect effects on microbial biomass, respiration, and metabolic diversity (Biologic and catabolic response profile) were compared seasonally after 9-13 years of vegetation control using repeated glyphosate applications in a replicated field study. Three pine plantations were selected to provide a range of soil characteristics associated with glyphosate binding (clay, Fe and Al oxide content) and site growing potential from the lowest to the highest in northern California. Glyphosate was toxic to bacteria and fungi from each plantation when grown in soil-free media. Culturable populations were reduced, as was the growth rate and metabolic diversity of surviving bacteria, by increasing concentrations of glyphosate. This toxicity was not expressed when glyphosate was added directly to soil, however. Microbial respiration was unchanged at expected field concentrations (5-50 mug g-1), regardless of soil, and was stimulated by concentrations up to 100-fold greater. Increased microbial activity resulted from utilization of glyphosate as an available carbon substrate. Estimated N and P inputs from glyphosate were inconsequential to microbial activity. Long-term, repeated applications of glyphosate had minimal affect on seasonal microbial characteristics despite substantial changes in vegetation composition and growth. Instead, variation in microbial characteristics was a function of time of year and site quality. Community size, activity, and metabolic diversity generally were greatest in the spring and increased as site quality improved, regardless of herbicide treatment. Our findings suggest that artificial media assays are of limited relevance in predicting glyphosate toxicity to soil organisms and that field rate applications of glyphosate should have little or no affect on soil microbial communities in ponderosa pine plantations.]

Cackowski, J.M., and Nasar, J.L. “The Restorative Effects of Roadside Vegetation: Implications for Automobile Driver Anger and Frustration.” **Environment and Behavior**. Nov. 2003. 35(6) pp736-751.
[This study addresses whether highway vegetation can mitigate automobile driver anger and frustration. Previous studies have shown that stress and/or fatigue from the exercise of directed attention can exacerbate anger and frustration, and that exposure to vegetation can facilitate recovery from this stress and fatigue. In the current study, 106 participants were randomly assigned to view one of three videotapes of highway drives, which varied in the amount of vegetation versus man-made material. The experiment obtained Speilberger State-Trait Anger Expression Inventory measures of anger before and after video exposure and obtained a measure of frustration tolerance after the video. Results for frustration tolerance showed higher frustration tolerance (respondents spent more time on unsolvable anagrams) after exposure to videotapes with more vegetation, although there was no similar effect on anger. These findings indicate that roadside vegetation can have a restorative effect on frustration reduction.]

Cedergren, Harry. “Grain Size vs Dollars for Drainage Aggregates.” **Civil Engineering-ASCE**. Nov. 1967.

Chen, C.Y., et al., eds. Hathaway, K.M., Folt, C.L. “Multiple stress effects of Vision herbicide, pH, and food on zooplankton and larval amphibian species from forest wetlands.” **Environ Toxicol Chem**. Apr. 2004. 23(4). 823-31. Department of Biological Sciences, Dartmouth College, Hanover, New Hampshire.
[As part of a multiple-tier research program, interactions of the herbicide Vision (glyphosate) with two stressors, pH and food level, were examined. Effects of the formulated product Vision were tested at two test concentrations (0.75 and 1.50 mg acid equivalent/L), two pH levels (pH 5.5 and 7.5), and under high and low food concentrations. Effects of each stressor alone and in combination were examined using two common wetland taxa: Zooplankton, Simocephalus vetulus, and tadpoles (Gosner stage 25) of Rana pipiens. For S. vetulus, survival, reproduction, and development time were measured; survival was measured for R. pipiens. For both species, significant effects of the herbicide were measured at concentrations lower than the calculated worst-case value for the expected environmental concentration ([EEC], 1.40 mg acid equivalent/L). Moreover, high pH (7.5) increased the toxic effects of the herbicide on all response variables for both species even though it improved reproductive rate of S. vetulus over pH 5.5 in the absence of herbicide. Stress due to low food alone also interacted with pH 5.5 to diminish S. vetulus survival. These results support the general postulate that multiple stress interactions may exacerbate chemical effects on aquatic biota in natural systems.]

Clarka, S.E., et al., eds. 1, Van Drieschea, R.G., Sturdevantb, N., Elkintona, J., and Buonaccorsic, J. P. “Effects of Site Characteristics and Release History on Establishment of Agapeta zoegana (Lepidoptera: Cochylidae) and Cyphocleonus achates (Coleoptera: Curculionidae), Root-Feeding Herbivores of Spotted Knapweed, Centaurea maculosa.” **Biological Control**. Vol. 22, Issue 2, Oct. 2001. 122-130.

a Department of Entomology, University of Massachusetts, Amherst, Massachusetts, 01003
c Department of Mathematics, University of Massachusetts, Amherst, Massachusetts, 01003
b United States Forest Service, Missoula, Montana, 59807
[We evaluated several factors to identify features or practices that might increase the probability of establishment following the release of two root-feeding insects (the cochylid moth Agapeta zoegana L. and the weevil Cyphocleonus achates Fahraeus) that attack the invasive plant, spotted knapweed (Centaurea maculosa Lamarck). At each of 99 sites where releases had been made in previous years, we assessed (1) the number of insects of each species released, (2) the number of years in which releases were made, (3) the number of years since the first release, (4) the size of the knapweed infestation, (5) its shape (linear, large single patch, many small patches), (6) the knapweed plant density, and (7–18) 12 physical site characteristics: habitat type, elevation, percentage slope, aspect, topographic type, forest structure at or by the site, disturbance factors, land use category, percentage forest canopy at or near site, percentage bare soil, annual precipitation, and soil type. We found that continuous, nonlinear patches of spotted knapweed on loamy soil that were surrounded by even-age forest stands had the highest rates of establishment for A. zoegana, but likelihood of establishment was not greater for larger releases (>200 adults). This suggests that roadside strips of knapweed should not be selected as release sites and that many, smaller releases (100–200 adults) are better than fewer, larger releases (300–500 adults or greater). For the weevil C. achates, we found that the probability of establishment was also greatest in continuous knapweed patches, rather than in strips, and that larger infestations (>2 ha) were better than smaller infestations. Establishment was also highest at mid-elevations (750–1500 m), compared to higher or lower locations.]

"Final Draft, Integrated Roadside Vegetation Management." **National Cooperative Highway Research Program (NCHRP), Synthesis of Highway Practice**. Washington DC: Transportation Research Board of the National Academies. Nov. 2003.

Forman, R.T.T., et al., **Road Ecology: Science and solutions**, Island Press, Washington, DC, 2003.

Hagen, S., et al., eds. Salisbury, S., Wierenga, M., Xu, G., Lewis, L. "Soil Bioengineeering as an Alternative for Roadside Management: Benefit-Cost Analysis Case Study." **Transportation Research Record.** 2002. pp97-104.
[As an environmentally compatible and cost-efficient alternative for roadside management, soil bioengineering has become increasingly important and attractive. Soil bioengineering uses live plants and plant parts as building materials for engineering and ecologically sound solutions to erosion control, slope and stream bank stabilization, landscape restoration, and wildlife habitats. However, not all decision makers are aware of the specific benefits of this approach. This case study applied a benefit-cost analysis to an experimental soil bioengineering demonstration project to evaluate the cost - effectiveness of soil bioengineering as an alternative to traditional roadside management. Traditional roadside management methods (geotechnical solutions) were used as the

baseline, and soil bioengineering treatments were treated as an investment alternative. Cost savings, along with other environmental benefits, were assessed and compared with construction costs. The effects of life cycle, effectiveness, and discounting were included in the analysis to ensure comparability between both treatments. The analytical results demonstrate that soil bioengineering methods, if technically feasible, could be adopted to produce equal or better economic and environmental results. The findings of the research project and the economic analysis indicate that soil bioengineering is an efficient and environmentally beneficial tool for roadside management.]

Harper-Lore, B.L. "Using Native Plants as Problem Solvers." **Environmental Management.** Nov. 30. 1996. 20(6) pp827-830.
[The Federal Highway Administration encourages state highway agencies to use native plants in erosion control, revegetation, and landscaping solutions. This paper explains both policy reasons and technical reasons for the use of native plants. How native species can be used is shown through a roadside case study. Other applications of native plant use are explained through a plant community approach.]

Huang, Xinjiang, et al., eds. Pedersen, Theresa; Fischer, Michael; White, Richard; Young, Thomas M. "Herbicide runoff along highways.1. Field observations." **Environmental Science-and Technology**. 2004. 38(12): 3263-3271.
[Herbicides are widely applied along highways to control roadside vegetation, and surface water is frequently nearby. To determine whether herbicide runoff along highways threatens water quality, a field study was conducted at two sites in northern California for three rainy seasons. The herbicides oryzalin, isoxaben, diuron, glyphosate, and clopyralid were selected for study to include compounds with significant variation in physical/chemical properties. Concentrations of herbicides in runoff were monitored for up to 11 storms following herbicide application, and 24 samples were collected per storm, providing unprecedented temporal detail. Flow-weighted event mean concentrations were calculated for each herbicide in each storm and ranged from below detection limits to 43.13,mug/L for oryzalin. The least soluble compounds, isoxaben and oryzalin, were detected in all storms monitored while the more soluble compounds, diuron and clopyralid, declined to levels below detection limits before monitoring was concluded. Very small amounts of glyphosate were mobilized, but its transformation product aminomethylphosphonic acid was detected at higher concentrations, in more storm events, and at greater depth in the soil profile. A first-order model successfully described the declining herbicide concentrations in spray zone soil and in surface runoff for all sites and herbicides. Fitted first-order coefficients were always higher for runoff than for soil, indicating that the herbicide that persists in the source zone becomes less available for runoff as the time since application increases. The percentage of the applied herbicide that was detected in surface runoff over a season ranged from 0.05% to 43.5%, and the most critical variables in controlling the variation were the solubility of the herbicide and the runoff volume. For a given herbicide and site, the most critical factors in determining seasonal herbicide loss to surface water were the timing and intensity of the first storm following application, affecting total seasonal runoff by up to 2 orders of magnitude. Minimizing runoff of herbicides along highways will thus require careful attention to the intrinsic mobility of the compound and the timing of its application.]

Huang, Xinjiang, et al., eds. Pedersen, Theresa; Fischer, Michael; White, Richard; Young, Thomas M. "Herbicide runoff along highways. 2. Sorption control" **Environmental Science- and Technology.** 2004. 38(12): 3272-3278.
[Controversy remains about the importance of nonlinear sorption isotherms, desorption rate limitations, and aging effects, collectively referred to as nonideal sorption processes, in controlling the fate and transport of organic contaminants. Herbicide runoff from highway soils represents a good test case for assessing the relative importance of nonideal sorption because runoff flow rates are often high, soil-water contact times are short, and significant time is available for contaminant aging after application. This study examines the sorption and desorption of five herbicides with a wide range of properties (isoxaben, oryzalin, diuron, clopyralid, and glyphosate) on soil samples from two roadsides in northern California and uses the results to examine field runoff data from multiple rainy seasons. Nonideal sorption processes do not appear to be significant in determining herbicide runoff at the field sites because (i) sorption isotherms were linear or slightly nonlinear for all compounds but glyphosate, (ii) field runoff concentration ratios between isoxaben and oryzalin were consistent with linear partitioning predictions, (iii) runoff leaving the site appeared to be in equilibrium with local soil concentrations, and (iv) desorption distribution coefficients for aged herbicides on soil samples collected from the field site did not differ substantially from those obtained in short-term laboratory adsorption experiments. Collectively, these findings indicate that linear equilibrium models are adequate for predicting the concentration of herbicides in runoff in these field settings and that more complicated nonideal models do not need to be invoked. Vegetated slopes effectively reduced the herbicide loads, with average removals of 35-80% occurring as runoff traversed a 3-m segment 1 m from the edge of the spray zone.]

Lee, Jinsun, and Mannering, Fred. "Impact of roadside features on the frequency and severity of run-off-roadway accidents: an empirical analysis." **Accident Analysis and Prevention**, Vol. 34(2) March 2002.
[In the U.S., single-vehicle run-off-roadway accidents result in a million highway crashes with roadside features every year and account for approximately one-third of all highway fatalities. Despite the number and severity of run-off-roadway accidents, quantification of the effect of possible countermeasures has been surprisingly limited due to the absence of data (particularly data on roadside features) needed to rigorously analyze factors affecting the frequency and severity of run-off-roadway accidents. This study provides some initial insight into this important problem by combining a number of databases, including a detailed database on roadside features, to analyze run-off-roadway accidents on a 96.6-km section of highway in Washington State. Using zero-inflated count models and nested logit models, statistical models of accident frequency and severity are estimated and the findings isolate a wide range of factors that significantly influence the frequency and severity of run-off-roadway accidents. The marginal effects of these factors are computed to provide an indication on the effectiveness of potential countermeasures. The findings show significant promise in applying new methodological approaches to run-off-roadway accident analysis.]

National Transportation Research Board, “Liability of the State for Injury or Damage Occurring in Motor Vehicle Accident Caused by Trees, Shrubbery or Other Vegetative Obstruction Located in Right-of Way or Growing on Adjacent Private Property.” **Legal Research Digest**. NCHRP (National Cooperative Highway Research Program, National Transportation Research Board). 1993.

National Transportation Research Board, “Integrated Roadside Vegetation Management: A synthesis of highway practice,” (R. Berger, Consultant) Report Number 341, National Cooperative Highway Research Program, 2005.

Pauchard, Anibal, and Alaback, Paul B. “Influence of Elevation, Land Use and Landscape Context on Patterns of Alien Plant Invasions Along Roadsides in Protected Area of South-Central Chile.” **Conservation Biology**. 2004. 18(1): 238-248.
[Alien plant species are a growing concern in protected areas, yet little information is available on the role of roads as corridors for alien species and the effects of elevation, land use, and landscape context in these invasions. These concerns are of particular interest in temperate zones of South America, where protected areas have high concentrations of endemic species. We studied roadside alien plant communities and forest-road edges in Villarrica and Huerquehue national parks in the Andean portion of south-central Chile. We sampled alien species and their abundance along 21 km of roads inside parks and 22 km outside parks, using 500-m roadside transects. We also sampled plant species and recorded their abundance in 15 transects located perpendicular to forest-road edges in four forest types. Of the 66 alien species encountered along roadsides, 61 were present outside parks and 39 inside parks. Elevation and alien species richness along roadsides were significantly and negatively correlated ($R2 = -0.56$, $p < 0.001$). Elevation, land use, and their interaction explained 74% of the variation in alien species richness along roadsides ($p < 0.001$). Transects located in pasture or disturbed secondary forests had significantly more alien species. We found no significant edge effect on native and alien species richness in any forest type. Few alien species have percolated into forest interiors. Native and alien diversity in edge plots were not related. Almost half the alien species belonged to three families and 85% were native to Eurasia. Our results suggest that alien species are moving into parks along road corridors and that elevation and land use of the matrix influence these invasion processes. Our findings corroborate the importance of early detection and control of invasive species in protected areas and highlight the importance of considering surrounding matrix land use in developing conservation strategies for reserves.]

Rea, Roy V. “Modifying roadside vegetation management practices to reduce vehicular collisions with moose Alces alces.” **Wildlife Biology**. 2003. 9(2): 81-91.
[Vegetation management practices currently used within transportation corridors are primarily aimed at minimising encroaching shrub and tree growth in order to increase driver visibility and road safety. Such practices create prime foraging habitat for ungulates such as moose Alces alces by inhibiting forest succession and maintaining early seral shrub communities. Increased foraging activity within the corridor increases the likelihood of encounters between moose and motorists. Moose-related vehicular collisions are costly in terms of material damage claims and have significant negative

impacts on public safety and moose populations in many parts of their range. Although several countermeasures have been developed in an attempt to reduce the frequency of these collisions, few have proven effective and even fewer have taken into consideration possible links between roadside vegetation management, the quality of browse regenerating from cut vegetation, and how moose use browse within the transportation corridor. To better understand these relationships, I reviewed the literature on ungulate-related vehicular collisions in combination with literature on plant response to mechanical damage. Many authors recognise the need to reduce the attractiveness of vegetation growing within transportation corridors. To date, diversionary feeding, forage repellents, establishment of unpalatable species and elimination of roadside brush have been used. Unfortunately, such techniques are only semi-effective or are not cost-efficient when applied across the landscape. It has long been recognised that the ability of plants to regenerate following mechanical damage is influenced by the timing of damage. Current research suggests that the quality of regenerating plant tissues for herbivores also depends on when plants are cut. Plants cut in the middle of the growing season produce regrowth that is high in nutritional value for at least two winters following brush-cutting as compared to plants cut at other times of the year, and uncut controls. Because roadside brush is generally cut during mid-summer, possible links between the quality of regenerated browse and increases in ungulate-related vehicular collisions during the autumn and winter should be elucidated. Based on this review, I recommend cutting brush early in the growing season and emphasize the need for collaborative long-term research to properly address this issue.]

Relyea, Rick A. "Predator cues and pesticides: A double dose of danger for amphibians." **Ecological Applications**. 2003. 13(6): 1515-1521.
[Amphibians are declining globally, and biologists have struggled to identify the causes. Pesticides may play a role in these declines, but pesticide concentrations in nature often are low and considered sublethal. Past research has found that the globally common pesticide carbaryl can become more lethal under different environmental conditions including differences in temperature and competition. A recent study has found that predatory stress, a situation common for most amphibians, can make carbaryl 2-4 times more deadly to gray tree frogs (Hyla versicolor). To determine whether this is a general phenomenon in amphibians, I examined how carbaryl affected the survival of six amphibian species in the presence and absence of predatory stress. Higher concentrations of carbaryl caused higher mortality. In two of the six species, carbaryl became even more lethal when combined with predatory stress (up to 46 times more lethal). This suggests that apparently safe concentrations of carbaryl (and perhaps other pesticides with similar modes of action) can become more deadly to some amphibian species when combined with predator cues.]

Relyea, Rick A. "Controlling pests and killing amphibians." **Ecological Society of America Annual Meeting Abstracts**. 2003. 88: 279.

Relyea, Rick A. "Growth and survival of five amphibian species exposed to combinations of Pesticides." **Environmental Toxicology and Chemistry**. 2004. 23(7): 1737-1742.

[The global decline of amphibians has sparked interest in the role that pesticides may play. Pesticides in nature typically exist in combinations, but given the vast number of chemicals used, most toxicological experiments necessarily have examined one pesticide at a time. I examined how four commercial formulations of pesticides (diazinon, carbaryl, malathion, and glyphosate) affected the survival and growth of five larval amphibian species (Rana pipiens, R. clamitans, R. catesbeiana, Bufo americanus, and Hyla versicolor) when alone (at I or 2 mg/L of active ingredient) and in pairwise combinations (I mg/L of each pesticide). At I mg/L, the pesticides reduced survival in 5% of the 20 species-pesticide comparisons and reduced growth in 35% of the comparisons. At 2 mg/L, the pesticides had more widespread effects, reducing survival in 35% of the 20 species-pesticide comparisons and reducing growth in 70% of comparisons. Combined pesticides occasionally caused lower survival and growth than either pesticide alone, but the effects were never larger than the more deadly of the two pesticides alone at 2 mg/L. This suggests that the impact of combining these four pesticides is similar to that predicted by the total concentration of pesticides in the system.]

Ricci, Paolo F., Cox, Louis A., and MacDonald, Thomas R. "Precautionary principles: a jurisdiction-free framework for decision-making under risk." **Human and Experimental Toxicology**, Dec 2004 v23 i12 p579(22).

Santos, A., and Flores, M. "Effects of glyphosate on nitrogen fixation of free-living heterotrophic bacteria." **Letters in Applied Microbiology**. 1995. 20(6): 349-352.
[The effect of the herbicide glyphosate (N-(phosphonomethyl)glycine) on the growth, respiration and nitrogen fixation of Azotobacter chroococcum and A. vinelandii was studied. Azotobacter vinelandii was more sensitive to glyphosate toxicity than A. chroococcum. Recommended dosages of glyphosate did not affect growth rates. More than 4 kg ha-1 is needed to find some inhibitory effect. Specific respiration rates were 19.17 mmol O-2 h-1 g-1 dry weight for A. chroococcum and 12.09 mmol h-1 g-1 for A. vinelandii. When 20 kg ha-1 was used with A. vinelandii, respiration rates were inhibited 60%, the similar percentage inhibition A. chroococcum showed at 28 kg ha-1. Nitrogen fixation dropped drastically 80% with 20 kg ha-1 in A. vinelandii and 98% with 28 kg ha-1 in A. chroococcum. Cell size as determined by electron microscopy decreased in the presence of glyphosate, probably because glyphosate induces amino acid depletion and reduces or stops protein synthesis.]

Schor, H.J., and Gray, D.H. "Landform Grading and Slope Evolution." **Journal of Geotechnical Engineering.** Oct. 1995. 121(10) pp729-734.
[To accommodate transportation corridors and residential developments in steep terrain, some grading is required. The manner in which grading is planned and carried out and the resulting topography that are created affect the aesthetic appeal of the development, the long-term stability of the slopes, and the effectiveness of landscaping and revegetation efforts. Conventionally graded slopes are essentially planar slope surfaces with constant gradients. Most natural slopes, though, consist of complex landforms covered by vegetation that grows in patterns that are adjusted to hillside hydrogeology. The authors analyze slope evolution models and determine that a planar slope is often not an equilibrium configuration. Landform-graded slopes, however, mirror stable natural slopes

and are characterized by a range of shapes, including convex and concave forms. Downslope drains either follow natural drop lines in the slope or are hidden from view in swale-and-berm combinations. Landscaping plants are patterned as nature, not randomly or in artificial configurations. The minimal increase in the costs of engineering and design for landform grading are offset by improved visual and aesthetic impact, quicker regulatory approval, decreased hillside maintenance and sediment removal costs, and increased marketability and public acceptance.]

Schrader-Frechette, K., and McCoy, E. **Method in Ecology: Strategies for Conservation**, Cambridge University Press, Cambridge, UK, 1993.

Sih, Andrew, et al., eds. Bell, Alison M.; Kerby, Jacob L. "Two stressors are far deadlier than one." **Trends in Ecology and Evolution**. 2004. 19(6): 274-276.
[Natural organisms often face a barrage of stressors, both natural and human induced. Two known stressors that impact amphibian populations are pesticides and predators. Recent work by Relyea and by Mills and Relyea reveals strikingly strong, synergistic negative effects of these two factors on amphibian larvae. Adding predation risk on top of supposedly sublethal concentrations of a common pesticide caused a massive increase in larval mortality. Interestingly, the increased mortality did not require exposure to actual predation . That is, simply the 'smell of danger' (predator chemical cues) caused 80-90% of larvae that were held in otherwise 'safe' levels of the pesticide to die. Notably, this effect occurred in some species, but not in others. These new studies highlight the need for further interdisciplinary work on the conditions under which combinations of stressors have particularly strong negative effects on natural organisms.]

Simberloff, D. "How Much Information on Population Biology Is Needed to Manage Introduced Species?" **Conservation Biology**. 2003. 17(1) pp. 83-92.

Slaughter, D.C., et al., eds. Giles, D.K; Tauzer, C. "Precision Offset Spray System for Roadway Shoulder Weed Control." **Journal of Transportation Engineering**. July 1999. Vol. 125, no. 4, pp. 364-371.
[A precision offset spray system was developed for use by highway maintenance departments for the control of unwanted vegetation in the graded shoulder area adjacent to roadways. The offset sprayer consisted of two fundamental elements: (1) a machine vision system; and (2) a rapid response intermittent spray system. This study showed that it is feasible to use machine vision on a moving vehicle to automatically detect the presence of green plant material and to apply herbicides exclusively to plants and not to nonplant materials (e.g., vegetation-free soil). The system substantially reduced the amount of herbicide applied to non-plant material. In system tests, there was up to a 97% reduction in applied spray mix over conventional continuous spray applications with a plant deposition rate of 57% of continuous spray systems. Implementation of this technology would allow highway maintenance departments to reduce the cost of week control and the amount of chemical herbicides released into the environment, while maintaining current levels of weed control efficacy.]

Tsui, Martin T.K., and Chu, L.M. “Aquatic toxicity of glyphosate-based formulations: Comparison between different organisms and the effects of environmental factors.” **Chemosphere**. 2003. 52(7): 1189-1197.
[Glyphosate-based herbicides (e.g. Roundup(R)) are extensively used in the aquatic environment, but there is a paucity of data on the toxicity of the formulated products and the influences by environmental factors. In this study, the acute toxicity of technical-grade glyphosate acid, isopropylamine (IPA) salt of glyphosate, Roundup(R) and its surfactant polyoxyethylene amine (POEA) to Microtox(R) bacterium (Vibrio fischeri), microalgae (Selenastrum capricornutum and Skeletonema costatum), protozoa (Tetrahymena pyriformis and Euplotes vannus) and crustaceans (Ceriodaphnia dubia and Acartia tonsa) was examined and the relative toxicity contributions of POEA to Roundup(R) were calculated. The effects of four environmental factors (temperature, pH, suspended sediment and algal food concentrations) on the acute toxicity of Roundup(R) to C. dubia were also examined. Generally, the toxicity order of the chemicals was: POEA>Roundup(R)>glyphosate acid>IPA salt of glyphosate, while the toxicity of glyphosate acid was mainly due to its high acidity. Microtox(R) bacterium and protozoa had similar sensitivities towards Roundup(R) toxicity (i.e. IC50 from 23.5 to 29.5 mg AE/l). In contrast, microalgae and crustaceans were 4-5 folds more sensitive to Roundup(R) toxicity than bacteria and protozoa. Except photosynthetic microalgae, POEA accounted for more than 86% of Roundup(R) toxicity and the toxicity contribution of POEA was shown to be species-dependent. Increase in pH (6-9) and increase of suspended sediment concentration (0-200 mg/l) significantly increased the toxicity of Roundup(R) to C. dubia, but there were no significant effects due to temperature change and food addition.]

Wilkinson, P.L., et al., eds. Brooks, S.M; Anderson, M.G. “Investigating the effect of moisture extraction by vegetation upon slope stability.” **Hydrology in a Changing Environment Volume III.** Chichester W: John Wiley and Sons, Ltd., 1998. pp. 237-246.
[Landslides are a considerable economic hazard in terms of slope maintenance and design costs. The Roads Branch of Public Works Department (PWD) in Malaysia, for example, spent 125 Million Malaysian dollars over a three-year period (1994-1997) on a special maintenance programme for only 22 slopes along the East-West highway from Gerik to Jeli. It is critically important for government road agencies such as PWD Malaysia to assess maintenance solutions to slope stability problems and to optimise their annual budgets for road maintenance. With the advent of increasing computer power, engineers have been able to quantify the geotechnical and hydrological controls on slope stability. Using this knowledge, measures have been adopted to stabilise these potential hazardous slopes, including regrading, the use of gunite or chunam as a protective cover, berms, soil nails and geotextiles. The latest area of research, however, concerns the practice of bioengineering: vegetation can provide a low-cost, aesthetically pleasing solution to problems of slope stability. Vegetation-slope interactions are inherently complex, because several groups of interrelated variables (meteorological, physiological, hydrological and pedological) each have important implications for slope stability. The mechanisms whereby vegetation influences slope stability may be broadly classified as either hydrological or mechanical in nature. Each may have an adverse or beneficial

effect on slope stability. Indeed, under certain conditions the net effect of vegetation cover may actually be detrimental to slope stability.]

Young, Steve. "Natural Product Herbicide for Control of Annual Vegetation Along Roadsides." **Weed Technology**. 2004.

SECTION II. GOVERNMENT AGENCY "TOOLKIT" RESOURCES FOR SELECTING ALTERNATIVE PRACTICES

Department of Transportation, State of California. **California Roadsides: A New Perspective**. Jan. 1997.
[Contains comparisons of more than 40 alternative vegetation management strategies evaluated over a multi-year period.]

Department of Transportation, State of California. **Roadside Management Toolbox**. Nov. 2004: currently maintained online at http://www.dot.ca.gov/hq/LandArch/roadside-home.htm.
[Contains specific cost and effectiveness information for 15 different alternative management strategies.]

Washington State Department of Transportation. **Value Engineering Study for Whidbey Island's SR 20, Roadside Vegetation Management,** February 2005.

SECTION III. GOVERNMENT REPORTS

Al-Kaisi, Mahdi M., et al. **Infiltration Rates for Native and Reconstructed Prairies across Iowa**. Iowa Department of Transportation and Iowa State University. (No date.)

Bligh, R.P., et al., eds. Seckinger, N.R.; Abu-Odeh, A.Y.; Roschke, P.N.; Menges, W.L.; Haug, R.R. **Dynamic Response of Guardrail Systems Encased in Pavement Mow Strips.** Texas Transportation Institute, Texas A&M University, College Station, Texas; Texas Department of Transportation, Research and Technology Implementation, Austin, Texas; Federal Highway Administration, Washington, DC., Jan. 2004. 0109-0308 pp166.
[Pavement mow strips are being used to combat vegetation growth around guardrail posts. However, the effect of pavement post encasement on the crashworthiness of strong post guardrail systems has not been investigated. In this paper, the authors examined the performance of these systems using experimental testing and numerical simulation. Mow strip dimensions, materials, and depths are considered in addition to the presence of "leave-out" sections around posts. Seventeen configurations of wood and steel guardrail posts embedded in various mow strip systems and confinement conditions were subjected to dynamic impact testing with a bogie vehicle. The dynamic impact tests were numerically simulated, and full-scale mow strip system models were assembled using the validated subcomponent models. Based on predictive numerical simulations, the authors

selected a concrete mow strip with grout -filled leave-outs for full-scale crash testing. Crash tests of a steel post guardrail system and wood post guardrail system encased in the selected mow strip configuration were successful, and implementation recommendations are provided.]

British Columbia Ministry of Transportation, **Pest Management Plan for the Thompson-Okanogan Region**. Apr. 2002.

British Columbia Ministry of Transportation, **Invasive Plant Strategy for British Columbia**. Final Draft. Fraser Basin Council. Oct. 2003.

British Columbia Ministry of Transportation, **"**Highway Maintenance Specification Section, Chapter 6.10." **Roadside Vegetation Control**. Oct. 2003.

British Columbia Ministry of Transportation, **Agreement to reduce labor costs**. Nov. 2002.

Brown, Cynthia S., and Rice, Kevin J. **Inputs and Maintenance for Revegetation with Native Herbaceous Species.** University of California, Davis. Department of Agronomy and Range Science; California Department of Transportation, Division of New Technology and Materials Research. 2001.
[This report presents the results of three studies designed to investigate methods for optimal establishment, growth and management of native perennial grasses. Two studies were conducted in the median of Interstate 5, south of Sacramento, California. The first study evaluated the effects of decompacting soil to 76 cm and three seeding methods (broadcast, drill and hydroseed with 25% more seed than other methods) on the establishment and growth of four perennial grasses native to California . The second study was designed to test the use of (1) well-timed mowing, (2) mowing with broadleaf specific herbicides and (3) mowing with pre-emergence herbicides for promoting the establishment and long-term persistence of native perennial grasses. The report also presents the results of an experiment conducted on abandoned low fertility agricultural soils that investigated the effects on native perennial grasses of amending soils with compost and slow-release nitrogen fertilizer as well as application of different types and amounts of straw mulch. The experiments yielded knowledge about methods for establishment, growth and management of native perennial grass plantings, leading to an understanding of their true potential for erosion control, slope stabilization and creation of low-maintenance, weed-free roadside communities.]

Burnham, D., et al., eds. Prull, G.; Frost, K. **Non-Chemical Methods of Vegetation Management on Railroad Rights-of-Way.** Vermont Agency of Transportation, Montpelier, Vermont; Federal Transit Administration, Washington, DC. Dec. 2003. 9801-0312 pp55.
[The goal of this project was to evaluate non-chemical alternatives to vegetation control in railroad rights-of-way primarily through a demonstration project. The current status of alternative railroad weed control technology implementation in Europe and North America was reviewed. A vegetation control demonstration project was implemented

during the 2001 growing season on 30 miles of track, located in northeastern Vermont, owned and operated by the Saint Lawrence and Atlantic Railroad, Auburn, Maine. Wet infrared thermal technology designed and built by Sunburst Crop., Eugene, Oregon, was demonstrated within the context of an experimental implementation plan that included multiple treatment scenarios to evaluate optimal treatment intensity, and quantitative vegetation assessments to evaluate effectiveness in controlling vegetation. The prototype ballast weed control equipment was highly effective at killing treated vegetation, easy to operate, and adaptable to a variety of application platforms. As environmental, water quality, and human health concerns continue to add constraints on routine use of pesticides, other forms of vegetation management must be developed. Sunburst's technology offers an opportunity to incorporate an additional and effective tool to important resource management systems.]

Bruneau, A., et al., eds. Yelverton, F.; Cooper, R.; Johnson, C. **Low Maintenance Turfgrass and Management Systems for NC Roadsides.** North Carolina State University, Raleigh, Department of Crop Science, Raleigh, North Carolina; North Carolina Department of Transportation, Raleigh, North Carolina; Federal Highway Administration, Washington, DC. Nov. 1999. 9607-9906 pp40.
[This project indicated several potential methods that could significantly lower the required mowings of roadsides. The adaptability trials resulted in three cool season and two warm season species being recommended. The cool season species include turf type tall fescue, fine fescue, and bentgrass. Turf type fescue seed head production was as vigorous as Kentucky-31 during the spring of the year, however, turf type tall fescues ultimately required two fewer mowings than Kentucky-31 by year end. Fine fescues were recommended for their continued use in mixtures, especially in shaded regions. Bentgrass performed well under low maintenance conditions and required only one mowing for the year. Recommended warm season species include common bermudagrass and centipedegrass. Common bermudagrass demonstrated a vigorous establishment rate, requiring only two mowings for the year. Due to common bermudagrass' lack of cold tolerance it was only recommended for the Piedmont region of the state. Centipedegrass, while slow to establish from seed, demonstrated excellent survival under the low maintenance conditions of the project. Spring establishment from seed was crucial in surviving the first winter. Seeding centipedegrass was only recommended for the Piedmont region of the state. The plant growth regulator trials identified Plateau as being equal or superior to the traditional mixture of Telar plus Embark, for suppressing tall fescue seedheads. While timing the application is still critical, total seedhead suppression was achieved during the spring growing period.

Cain, N.P. **Wildflower and Prairie Seeding Recommendations for Ontario Roadsides.** Ontario Ministry of Transportation. Nov. 1997. p35.
[This report presents recommendations for wildflower and prairie seeding on highway rights-of-way in Ontario that have been developed as a result of Ministry research. Initially, experiences in other parts of North America were reviewed, which highlighted problems in roadside wildflower establishment. Companion research identified naturally occurring wildflowers on Ontario roadsides and explored work on tallgrass prairie and wildflower planting occurring in southern Ontario and neighbouring jurisdictions. Trial

seed mixtures were developed as a result of these investigations and tested in Ministry field trials. The characteristics of native wildflowers and prairie grasses suitable for roadside planting are discussed. Different native wildflower and prairie seed mixtures are presented that include herbaceous perennials selected to provide a flower show from early summer to late fall and to provide a self-sustaining ground cover. The prairie seed mixtures range from $450 - $2,600 to $4,000 - 13,200 ha-1 for pure live seed. Nurse grasses are recommended with the lupine and prairie grass seed mixtures to stabilize the area while the perennial plants establish. Information is provided on sources of seed, pure live seed determination and calculation of actual seeding rates. Ministry research has clearly demonstrated that existing vegetation must be controlled before planting in order to establish wildflower or prairie communities on vegetated sites. Site preparation may take a year or more depending on the species present. Smaller areas may be seeded by hand, but the use of a specialized seeder is necessary to seed larger areas. Best establishment of these seed mixtures results from a well-prepared seed bed, adequate seed/soil contact and firming of the seed bed after seeding. Methods of, equipment for and timing of seeding; and the application of fertilizer are discussed. Follow-up maintenance operations for both wildflower and prairie establishment depends on the objective of the planting and the growth of the undesirable vegetation. These seed mixtures have been designed for planting with no follow-up maintenance, but wildflower plantings could be mowed in late fall or early spring to provide a more even look to the site and to remove dead seed heads to improve the flower show the following growing season. Mowing or selective herbicide applications will prevent woody plant invasion that may be a problem on prairie sites. The use of controlled burns is another option for prairie plantings to control weeds and woody plants. This report provides a complete guide to different wildflower and prairie seed mixtures for Ontario roadsides and outlines the operations necessary for successful establishment.]

Center for Transportation Studies. **Best Practices Handbook on Roadside Vegetation Management**. University of Minnesota. 2000.

CALTRANS. “District 7 design directives, slope planting, edge groundcovers, mowing, replacement planting.” 2002.

CALTRANS. “Santa Cruz Weed Control Pilot Project CALTRANS District 5.” **News Release**. Apr. 2002.

CALTRANS. **California roadsides, a new perspective**. Jan. 1997.

California Department of Transportation. **California Roadsides: A New Perspective. Executive Summary.** Sacramento, California. Jan. 1997. pp20.
[The California Department of Transportation (Caltrans) manages approximately 15,000 mi (24,135 km) of highway and more than 230,000 acres (930,810,000 sq m) of right-of-way throughout California. A major portion of the management and maintenance effort is devoted to activities associated with vegetation control. Historical and current control methods have relied upon herbicides and mowing. Caltrans' vegetation management approach is changing as other values are being considered and new products and

alternatives emerge. Herbicide use may not be the sole or best answer in light of social values such as environmental quality and public concerns, or in the context of better roadside design and alternative treatments. In 1989, Caltrans began development of a programmatic environmental impact report (EIR) to assess the risks of its chemical control program for vegetation management. Following issuance of the final EIR in 1992, Caltrans adopted an integrated vegetation management program and set goals for reduction of chemical use: a 50% reduction by 2000 and an 80% reduction by 2012. This Executive Summary provides an overview of information presented in the comprehensive report, "California Roadsides: A New Perspective," on the results of a multi-year program for analyzing vegetation management strategies to meet these and other goals. This summary gives an overview of: the history of the vegetation management study program; the goals and objectives of the program; the vegetation management challenges that Caltrans faces; the study methods; and the results and recommendations of the study.]

Christopher, S. **Maintenance of Highway Edge Drains**. NCHRP Synthesis of HWY Practice #285, 2000.

Claussen, Vick. **Generation of water stable soil aggregates for improved erosion control and revegetation success**. CALTRANS Research Report # 53X461, Mar. 1998.

CROW-werkgroep Bestrijding kruidengroei op verhardingen. “Design Examples of Weed Inhibiting Pavements” (Ontwerpvoorbeelden onkruidwerende verhardingen). Publicatie 119, 1999 118p.
[Chemical weed control is increasingly regarded as an inappropriate method for the maintenance of pavements. Neither do alternative methods have the desired effects. This gives way to the growth of more weed, increasing cost and maintenance. Because many herbicides deal with symptoms and not with causes, preventive control of weed growth is looked for, i.e. prevention of the problem. Especially element paved areas are very easily covered with weeds because of their large quantity of open spaces (joints, potholes). If when designing those pavings, the open spaces are limited, weed growth will be limited at the same time. This book contains design examples of weed inhibiting pavements. There are six categories to be distinguished: edgings alongside roadways, cycle tracks, footpaths; small traffic islands; extended and average size traffic islands; holes for root systems of trees; footpaths and obstacles. Photographs of problem situations are shown for each category. Also design drawings and three-dimensional sketches are depicted representing possibilities for improvement. Adaptation of design and technical solutions alone do not solve the problem of weed growth on paving. In order to implement the adjustments and solutions. The organisation has to be adapted to that aim. A commission to the Board and working by projects serve as aids to that cause.]

Creech, M.F. “Deferred Maintenance – Roadside Vegetation and Drainage Facilities.”
CA: Byrd, Tallamy, MacDonald and Lewis, Falls Church, Virginia; Aug. 1977. pp124.
[The investigations in this study indicated that deferred maintenance was being practiced without adequately considering the consequences of such action. Emphasis in the study was placed primarily on the investigation of the consequences of deferring maintenance

activities and the formulation of a methodology for deferred maintenance program development to minimize the negative consequences. The major consequences of deferring maintenance that were reported on in this study were: safety; effect on the condition of highway facilities; liability; social effects; effects on the environment; level of service. The methodology for deferred maintenance program development was formulated in five steps. The five steps are: Identify maintenance objectives; Establish priorities for maintenance activities; Selection of deferment activity; Assigning the deferment prior; and Evaluating the consequences of deferment. The research was accomplished by a combination literature search and field study which included a visitation to six states.]

Creech, M.F. "Deferred Maintenance." **Transportation Research Record.** 1980. (776) pp15-22.
[This study investigated deferred maintenance as it concerned roadside vegetation control and drainage. It was also designed to develop the basis for a deferred maintenance program. Field work revealed that vegetation growth control, especially mowing, was being sharply reduced and that most states visited were rewriting their standards to reflect this. Maintenance deferral for drainage facilities, which are less visible, was even more dramatic; maintenance was performed on an as-needed basis, in many cases only when some catastrophic event such as flooding occurred. Major consequences of deferred maintenance were considered in relation to safety, condition of facilities, liability, social and environmental effects, and level of service. A methodology for developing a deferred maintenance program was formulated. This method, which consists of five discrete steps, has the potential to allow selection of maintenance activities to be deferred and determination of the deferment period that has a minimum of risk.]

Dunlap, D.W. "Pilot Study of the Influence of Vegetation and Other Factors on Pavement Condition." **Transportation Research Record**. 1991. (1326) pp11-14 (1 Tab.).
[Historically, the extent to which nonrhizomatous and nonstoloniferous vegetation, particularly grasses, on the road shoulder contributes to the premature deterioration of road pavement by impeding the off-surface flow of water has proven, in the absence of empirical evidence, to be controversial. Anecdotal evidence has been used to support the need to remove such vegetation. A pilot study was conducted to determine the relationship, if any, between the presence and abundance of road-shoulder vegetation and pavement condition ratings through an attempt to reveal the existence and strength of any correlation between the variables. Besides vegetation and pavement condition factors such as cracking and raveling, a number of other variables were investigated, including average daily traffic counts at the nearest road intersection, soil factors, roadway and shoulder grade, ditch condition, and canopy cover over the roadway. Whereas the purpose of the study was to collect and analyze data testing the null hypothesis that nonrhizomatous, nonstoloniferous vegetation does not cause premature pavement deterioration by impeding the off-surface flow of water, the purpose of this paper is to stimulate further research. The results of the pilot study indicate an apparent lack of association between the presence and abundance of shoulder vegetation and pavement condition because the correlation coefficient was not statistically significant. Other factors, however, are shown to be significantly correlated with pavement condition.

Therefore, the study should be expanded to account for the influence of factors not considered in the pilot study because of data gaps.]

Edgar, Rob. **Evaluation of Infrared Treatments for Managing Roadside Vegetation.** Oregon Department of Transportation, Research Unit, Salem, Oregon; Federal Highway Administration, Washington, DC. Dec. 2000. pp154.
[Environmental concerns have prompted many agencies to seek alternatives to herbicides in controlling vegetation on roadway shoulders. This study was implemented to evaluate the potential for infrared technology to address this need. Infrared technology uses radiant energy to kill unwanted vegetation. Intense heat generated by liquid propane coagulates plant proteins and bursts cell walls, killing seedling plants and destroying the tops of established vegetation. 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 (8, 6 and 4 treatments/year) along Oregon highways from November 996 through June 1999. These treatments were compared to shoulders treated with herbicides and to shoulders where vegetation was left unmanaged (control sites). Results suggest that infrared technology can keep vegetation under control on roadway shoulders.]

Elfering, J.M. **Improving the Design of Roadside Ditches to Decrease Transportation Related Surface Water Pollution.** University of Minnesota, St Paul, Minnesota, 2002. pp27.
[A field-monitoring program began in the spring of 2000 to test the ability of a grassy swale at removing pollutants in stormwater. In 2001, a check dam was designed in conjunction with Minnesota Department of Transportation (Mn/Dot) engineers and installed into the vegetative swale. The check dam system incorporated some unique design features including a peat filter to trap nutrients and metals; and a low rock pool to trap water for biological processing. The check dam was designed for cost effectiveness and simple installation. The entire system was quantified and evaluated hydrologically and qualitatively both before and after the check dam installation. Pollutants monitored included total suspended solids, total phosphorus, and orthophosphorus. The average pollutant removal rates for the three storms following the installation of the check dam were 54 percent total phosphorus, 47 percent orthophosphorus, and 50 percent total suspended solids. The results suggest that properly designed short vegetative strips and swales, which include peat and rock check dams can substantially reduce pollutant levels from the stormwater exiting roadways.]

Felsot, Allan. **Assessing the Safety of Herbicides for Vegetation Management in the Missoula Valley Region**. Final Report. A question and answer guide to human health issues. Washington State University, Pullman, Washington. Apr. 2001.

Fire Hazard Reduction Guide for Roadsides. California Division of Forestry and U.S. Forest Service, Region 5, January, 1968.

Hamilton, C.W., et al., eds. Bell, R.; Giblin, D.; Wolf, K.; Ewing, K. **Planting for Sustainable Roadsides: Empirical and Experimental Studies and Recommendations**

for Western Washington. Washington State Transportation Center, Seattle, Washington; Washington State Department of Transportation, Olympia, Washington. Federal Highway Administration, Washington, DC. Jul. 1998. pp304.
[Over a year and a half, research was conducted to assess the performance of selected plant materials on western Washington highway roadsides, to experimentally evaluate different soil covers for their effects on plant performance and weed control, to experimentally evaluate different site preparation techniques for their effects on plant performance, and to consider aesthetic perception as it might influence roadside landscape design. The ultimate goal is a highway roadside landscape that serves functional, ecological, and aesthetic purposes in a cost-effective manner sustainable over the long term. Evaluations of 12 roadside landscape sites and synthesis of performance data concerning 22 woody species - 14 native and 8 exotic - suggest that drought stress is the primary cause of poor plant performance, exacerbated by nutrient-poor, fast-draining sandy loam soils. All species, even those that perform well under such conditions, benefit from compost application at the time of planting. Species that are naturally adapted to water stress should be emphasized, including several natives that heretofore have been seldom utilized. Erosion-control mixes of aggressive exotic grasses often out-compete woody plants, to the long-term detriment of slope stability; native bunchgrasses and low shrubs are recommended instead. Invaders such as Himalayan blackberry are best controlled by herbicides, well timed mowing, and shading out by desirable native trees. Experiments suggest that soil covers of clover or weed mats suppress weeds more successfully than do bark mulch or Nutramulch plus residual herbicide. Clover, however, out-competed woody species for water, resulting in 95% mortality, so weed mats are clearly recommended where economically feasible. Parklike landscapes of well-spaced large trees and low understory densities are most positively perceived by observers. Such landscapes, however, may not be as functionally or ecologically appropriate, nor as cost effective, as "messier" landscapes. Therefore, designers of highway roadside landscapes are challenged to devise solutions that best meet local criteria for success.]

Harrigan, Edward T. “Performance of Pavement Subsurface Drainage.” **Research Results Digest**. No. 268. Nov. 2002.

Hauser, D. and W.G. McCully. **Presuppression of Roadside Fires**. Texas Transportation Institute, Research Report No. 902-7, 1993.

Jennings, S.R., et al., eds. Goering, J.D.; Blicker, P.S.; Taverna, J.J. **Evaluation of Organic Matter Compost Addition and Incorporation on Steep Cut Slopes, Phase I: Literature Review and Potential Applicable Equipment Evaluation.** Montana State University, Reclamation Research Unit, Bozeman, Montana; Montana Department of Transportation, Helena, Montana; Federal Highway Administration, Washington, DC.
[Erosion of steep highway cut slopes in Montana is the consequence of poor vegetation development in nutrient-poor growth media resulting from highway construction where topsoil cannot physically be replaced due to slope steepness. A literature review was conducted to synthesize available examples of compost application and incorporation on steep cut slopes to stimulate vegetation growth and retard erosion. Equipment applicable

to either compost application or incorporation on slopes steeper than 3(H):1(V) was identified. Candidate research test plot locations were evaluated and are described.]

Johnson, A.M. **Best Practices Handbook on Roadside Vegetation Management.** Professional Engineering Services, Limited, Wayzata, Minnesota; University of Minnesota, Minneapolis, Center for Transportation Studies, Minneapolis, Minnesota. Sep. 2000. pp132.
[Maintaining roadsides for safety and aesthetics is an important issue for all levels of government throughout Minnesota. Vegetation is one important element of roadside maintenance. This handbook provides guidelines for effective management of roadside vegetation for local agencies, and highlights seven best management practices that were identified through research, surveys, and discussion with industry experts. The seven best management practices for roadside vegetation fall into these seven categories: 1. Develop an integrated roadside vegetation management plan; 2. Develop a public relations plan; 3. Develop a mowing policy and improved procedures; 4. Establish sustainable vegetation; 5. Control noxious weeds; 6. Manage living snow fences; 7. Use integrated construction and maintenance practices. The main conclusion from the handbook is that successful roadside vegetation management depends on an integrated approach. This includes a wide variety of best management practices to address the many issues involved. This integrated approach includes an assessment of the existing conditions and determination of the type of roadside environment desired. Other construction operations, including proper seeding techniques, selection of the correct plant in the right area, selection of salt -tolerant seed species where needed, and erosion control, will greatly affect the roadside condition. Use of integrated construction and maintenance practices is one of the most important best management practices identified in the handbook.]

Johnson, L.A. **Managing Roadside Vegetation in Alaska. Final Report.** Alaska University, Fairbanks, Institute of Northern Engineering, Fairbanks, Alaska; Alaska Department of Transportation and Public Facilities, Engineering and Operations Standards, Juneau, Alaska; Federal Highway Administration, Washington, DC. Aug. 1995. pp27.
[This report examines the problem of controlling undesirable roadside vegetation, primarily tall wood shrubs and trees, in the central and northern districts of Alaska. Other vegetation management concerns, such as reestablishing vegetation on disturbed areas following road construction and maintaining desirable, low growing species along roadsides are briefly addressed. This report does not directly examine vegetation problems in the much wetter, maritime climate of Southeast Alaska. Roadside vegetation control is a costly, recurring problem for the Alaska Department of Transportation and Public Facilities (AKDOTandPF). Mechanical cutting is the dominant means of control presently, although herbicides were widely used in the past, and these have had some recent but limited use in Southeast Alaska. To reduce most effectively the extent of undesirable woody species along the roadside, it is preferable to use multiple methods, such as mechanical cutting in conjunction with a limited basal spray (herbicide) program or with hand weeding. Such an integrated vegetation management (IVM) approach will help reduce both the number of species as well as the number of individual woody plants that might persist. On the basis of this project, it is recommended that AKDOTandPF

develop a long term IVM program that includes vegetation monitoring and a maintenance program to enhance desirable vegetation along roadsides.]

King County, Washington, **Roadside Weed Control Program Monitoring Report**. Road Services Division, King County Department of Transportation, Seattle, Washington. 2003.

Kirchhoff, C., et al., eds. Malina, J.F. Jr.; Barrett, M.E. **A Review and Evaluation of Literature Pertaining to Compost Characteristics and to the Application of Compost Alone and Mixed with Different Soils.** University of Texas, Austin, Center for Transportation Research, Austin, Texas; Texas Department of Transportation, Research and Technology Implementation, Austin, Texas; Federal Highway Administration, Washington, DC. Jul. 2002. 0106-0208 pp64.
[The Texas Department of Transportation (TxDOT) reports that composted manures have been used in 22 of the 25 TxDOT districts, usually with excellent results. The application of composted manures to rights-of-way successfully improved growth of vegetation and controlled erosion of slopes on highway embankments. However, consistent availability of compost of the quality and quantity required for use in roadside projects is problematic in some states. Many sates have adopted specifications for compost characteristics to ensure consistent quality of compost. The objectives of this literature evaluation are identification of the constituents and composition of various types of composted materials including animal manures, municipal wastes (solid waste and wastewater sludges), and other waste materials, as well as documentation of application of the composted materials alone as well as mixed with different soils (composted manufactured topsoil). Most compost has a pH in the neutral range, organic matter content ranges from 30% to 60%, moisture content ranges from 30% to 50%, and the concentrations of N, P, K, and salts are higher than those typically found in agricultural soils. Compost addition to soil is considered Compost Manufactured Topsoil (CMT). CMT has improved soil structure, reduced bulk density, increased permeability, and increased aggregate stability compared to soil alone. These improvements reduce erosion and increase the water holding capacity of CMT. CMT also increased availability of soil nutrients, microbial population and activity, and reduced the incidence of soil nematodes and other pathogens. Potential problems with compost use include water quality impacts caused by nutrient loss and leaching of high salt concentrations, as well as potential accumulation of heavy metals in the soil zone.]

Kulkarni, R., et al., eds. Finn, F.; Golabi, K.; Johnson, R.; Alviti, E. “Maintenance Levels of Service Guidelines.” **NCHRP Report**. Jun. 1980. pp118.
[Highway maintenance managers, at state and district levels, will find this report helpful in the difficult task of establishing levels of service for different elements of a highway that are consistent with regard to multiple and often conflicting conserations such as safety, riding comfort, economics, environmental impact, protection of investment, and aesthetics. Systems analysts will find the report helpful in explaining the application of decision analysis principles to maintenance planning. The report provides a procedure that allows for different levels of service to be established for various maintenance conditions, road classifications, and local values. Local values are reflected in the levels

of service through systematic assessment of tradeoffs between different considerations. A given road or system of roads provides varying levels of service to the road user. Maintenance levels of service influence the magnitude of the maintenance work (e.g., pavement patching, mowing, paint striping) and, therefore, the work scheduling requirements, work priorities, and resource allocations. Selection of the maintenance level of service is influenced by a number of considerations that include safety, rideability, economics, environmental impact, protection of investment, and aesthetics. To optimize the expenditure of maintenance resources, there has been a need to develop a systematic and objective method to establish maintenance levels of service guidelines for all maintenance elements of the highway (such as pavement surface, shoulder, vegetation, signs, structure, drainage ditches). Such a method has been successfully developed and demonstrated in two states for pavement edge drop-off and vegetation control. This report describes the method and the procedures to follow in applying the method.]

LaRoche, R., and LaRoche, G. **Evaluation of Crown Vetch (Coronilla Varia) as a Sustainable Vegetation for Roadsides.** Maine Department of Transportation, Augusta, Maine; Federal Highway Administration, Washington, DC. Mar. 2001. pp20.
[The Maine Department of Transportation needs to control unwanted woody plant growth along its roadsides in order to maintain safe roadways. Traditional methods to control this unwanted growth include hand cutting, mechanical mowing, and the application of herbicides. All of these methods have drawbacks which include expense, exposure to personal injury, use of large amounts of fossil fuel, and negative public perception. This project looks at an alternative means to controlling unwanted brush by establishing plant species that will compete with and suppress its growth. Crown Vetch has been identified as a plant that will meet this need. Current seed bed preparation and seeding rates are based on establishment under new construction, vegetation-free ground conditions. Presently there is a reduced amount of new construction projects while there is a great number of miles of existing roadside. This research looks into ways to successfully establish Crown Vetch into existing vegetation. Two sites were chosen, one in Bowdoinham, Maine and the other in Benedicta, Maine. Variables identified and tested were: 1) Treatment of site to enhance growth; 2) Varying the rate of seed application per one thousand square feet; and 3) Sowing the seed at different times of the year. To test these variables a randomized complete block design using twelve treatments and replicated three times was established at both sites during May, July, and October. The treatments consisted of three site preparation methods: cut existing vegetation, kill existing vegetation with a herbicide, and no treatment using four seeding rates.]

Mahosenaho, T., Pirinenen, T. “Establishing Meadow Vegetation on Road Verges: Study Results and Literature Review.” **TIELAITOKSEN SELVITYKSIA.** 1999.(12).
[Interest in constructing natural roadside green areas has increased lately. Road areas have become wider, while funds for management have come down. There is a need to minimise maintenance resource use. With poor soil and low-growing meadow vegetation instead of a lawn the number of cuttings can be reduced. Using native wild flowers in some places instead of the Finnra standard seed mix of foreign origin is better for biological diversity. Roadside verges offer a high diversity of habitats and are important for the survival of many rare and endangered plant species. The roadside is, on the other

hand, a very difficult habitat (pollution from vehicle exhausts, dust, road salt, wind gusts from traffic etc.).]

Maryland Department of Transportation. **Integrated Vegetation Management Manual for Maryland Highways**. Oct. 2003.

McGruthry. **Pavement Subsurface Drainage Systems**. NCHRP Synthesis of HWY Practice #239, 1997.

Meunier, Francis D., et al., eds. Verheyden, Christophe, and Jouventin, Pierre. **Use of roadsides by diurnal raptors in agricultural landscapes**. Centre d'Etudes Biologiques de Chizé, France.
[In a 2772 km survey in western France, we compared the relative abundance and activity of diurnal raptors along motorway verges and secondary roads to those in open cropland, during different seasons and hours of the day. Motorway verges, and to a lesser extent secondary road verges, were used significantly more than adjacent areas by buzzards (Buteo buteo), kestrels (Falco tinnunculus) and black kites (Milvus migrans), but not by harriers (Circus aeruginosus, C. cyaneus, C. pygargus). There was a seasonal shift in the use of "roadsides" by buzzards and kestrels, with a high use of motorway verges in winter and a low use in summer. Although kestrels and buzzards clearly used verges for hunting, their abundance along roads was not directly related to the relative abundance of small mammals. The supply of perching sites, allowing a less energy-demanding hunting behaviour than flight-hunting, and the width of the verges, appeared important factors in the attractiveness of "roadsides" for these species. This study shows that "roadsides," particularly wide motorway verges, can be managed with respect to the conservation and abundance of raptor species in agricultural landscapes, in providing stable prey habitats and perching sites.]

Ministry of Transportation, British Columbia. "Chapter 6.10: Roadside Vegetation Management." **Best Management Practices for Highway Maintenance Activities**. 2004.

Minnesota DOT Maintenance Northwest District Two, **Integrated Vegetation Management Plan for 2002**. 2002.

Minnesota DOT District One. **Integrated Vegetation Management Program Manual**. Mar. 1999.

Minnesota DOT Maintenance Area 7A. **Integrated Vegetation Management Plan for 1998**. 1998

Minnesota DOT Metro Division/Twin Cities Area. **Integrated Vegetation Management Plan for 2002**. 2002.

Minnesota DOT. "Partial List of Pest Situations and Possible Pesticide/Control Products for MnDOT Vegetation Management on Rights of Way." 2003.

Minnesota DOT. “Brush Control Situations, Partial List of Chemicals and Tools for Minnesota DOT Roadside Management Applications,” 2003.

Minnesota DOT Policy Position Statement. May.1984.

Montana DOT. **Statewide Integrated Weed Management Plan 2003-2008**. 2003.

Montana DOT. **The Montana Weed Management Plan**. Weed Summit Steering Committee and Weed Management Task Force. Jan. 2001.

Montana DOT. **Lewis and Clark County Integrated Weed Management Plan: 2003-2008**. 2003.

Montana DOT. **Phillips County Integrated Weed Management Plan: 2003-2008**. Montana DOT. 2003.

Williams, Dan. “Montana DOT (MDT) Roadside Management.” Slides. (No date.)

Montana DOT. **Placement Topsoil and Seeding the Gravel Surfacing Inslopes, for establishing beneficial vegetation**. 2001.

National Roadside Vegetation Management Association. Newark, Delaware. **How to Develop and Implement an Integrated Roadside Vegetation Management Program: A Guide for Township, City, County, Parish, State, Turnpike and Other Roadside Authorities.** Mar. 1997. pp44.
[This guide has been developed to assist those agencies, public or private, that are charged with the responsibility to manage and control roadside vegetation. It is intended to be a planning document that will enable each user to develop a management plan that will recognize the specific needs and unique characteristics of their particular location or area. It does not provide an ideal vegetation management plan. It provides a proven process to enable development of an appropriate management plan. The guide includes ideas for resource information and incorporates some best practices that have proven to be successful in various locations throughout the United States.]

NCHRP. **Improved Surface Drainage of Pavements: Final Report.** Web Doc. 16, Transportation Research Board. 1998.

Pan, Y., et al., eds. Foster, E.; Vaivoda, A. **Effects of Bromacil Diuron, Glyphosate, and Sulfometuron-Methyl on Periphyton Assemblages and Rainbow Trout**. Portland State University, Environmental Science and Resources, Portland, Oregon; Oregon Department of Transportation, Salem, Oregon; Federal Highway Administration, Washington, DC. Apr. 2003. pp43.
[This study documents the testing of several common herbicides used by the Oregon Department of Transportation in vegetation management. The project assessed the short- and long-term effects of Roundup, Krovar and Oust on periphyton and rainbow trout. The active ingredient in Roundup is glyphosate; Krovar uses bromacil and diuron; and Oust

uses sulfometuron-methyl. Short-term (96-hour) exposure tests used actual road shoulder runoff collected after herbicide application, using a simulated rain and a natural rain event. Long -term exposure tests assessed effects of a 14-day exposure using lab-mixed solutions of deionized lab water and herbicides, individually and in mixture. The data showed that the short-term exposure had no statistically significant effects on periphyton. The short-term exposure reduced survivorship of rainbow trout, but the effects were observed both in treated and untreated runoff; thus the toxicity was likely due to other factors. The long-term exposure tests showed that herbicides, especially Krovar and the mixture of three chemicals, reduced periphyton algal biomass. The declined trend in biomass was more evident in live cell density than in chlorophyll a concentration, suggesting that algal responses to chemicals may vary among groups (green algae vs. diatoms). The long-term exposure had no statistically significant effects on fish mortality and dry weight. Individual herbicide bioassays showed no significant differences between the changes in wet weight, but significant differences in wet weight were found between treatments in the mixture bioassay. The study showed that periphyton assemblages could be altered by some chemicals. While rainbow trout fish showed no statistical effects for dry weight, the effect on other sublethal endpoints remains a possibility.]

Pruett, M. “Integrated Vegetation Management on Los Angeles County Roads.” **Transportation Research Record**. 1981. (805) pp19.
[In prior years, the County either denuded the system through mechanical means or a surface application of oil; however, incresing costs have led to the adoption of longer-lasting chemical treatments. The use of the highly efficient herbicides in roadside vegetation control has greatly reduced our time commitment to this discipline. The chemicals used in the past season include Hyvar X and Korvar I in the coastal plains. Lorox was used in areas requiring short-term control, Fenamine used for Russian thistle control, Princep 80 used in the mountain areas near pine trees, and Phytar 560 used for spot treatment in the spring. Economics is a key reason for the use of chemicals in a vegetation control program. The development of herbicides has made it possible for many maintenance units to virtually eliminate hand cutting of brush and weeds. Weed-free highway rights-of-way can be an important part of any district's good neighbor policy.]

Rinard, J.E. “Roadside Vegetation Management in Idaho.” **Transportation Research Record.** 1986. (1075) pp11-14.
[The objective of roadside vegetation maintenance on Idaho's highways is to provide "a low-growing grass on the shoulder-foreslope areas and a mix of taller grasses, forbs, flowers, shrubs or trees beyond the shoulder to the right-of-way boundary." To accomplish this, vegetation establishment work is classified as landscape or functional. Landscape projects are classified as high, medium, or low level with regard to maintenance costs and are planned and maintained accordingly. Functional revegetation projects, which make up the major roadside effort in Idaho, are planned according to four climatic zones, using eight different grasses and three legumes, plus natives and additional grass varieties for problem areas. Maintenance of the functional projects is carried out through five phases from early spring to late fall and involves the coordination of spraying, blading, mowing, brush clearing, reseeding-planting, and fertilization. This

program, intended to hold maintenance costs at the lowest possible level and comply with state weed laws, has resulted in an overall cost reduction in functional roadside maintenance of nearly 21 percent during the last 3 years.]

Sanders, M.R. **Investigation of Waste Tires in Landscaping Applications.** South Carolina Department of Transportation, Columbia, South Carolina; Federal Highway Administration, Washington, DC. Oct. 2000 9709-0010 pp30.
[In 1991, the South Carolina Legislature passed the South Carolina Waste Policy Management Act requiring the South Carolina Department of Transportation to pursue the use of certain waste materials in highway construction and maintenance operations. In an earlier research project, rubber, in the form of discarded tires, was identified as one of the state's most abundant waste materials with the potential for use in the highway industry. In 1997, landscaping products made from 94 tons of tires collected from illegal dumps in a portion of the state were placed at five of the Department's rest areas and welcome centers. The products included several sizes of loose mulch and vegetation mats. This study was initiated to evaluate the performance of the waste tire landscaping products. After three years, the waste tire landscaping products were considered to be performing satisfactorily. The rubber mulch had not deteriorated and little difference in color was noted. Attendants at the rest areas and welcome centers said the loose rubber mulch stayed in place better than traditional bark mulch. The vegetation mats were useful when placed in areas that were maintained. However, many were used in remote areas of the facilities and were covered with soil and grass by the end of the evaluation period. One negative aspect of the material is a very noticeable rubber smell particularly on hot, humid days. Also, the initial cost of the waste tire mulch is considerably higher than conventional wood mulch products. Cost comparisons showed that rubber mulch needed to last four to five years to be cost effective, assuming wood mulch was replaced yearly.]

Slaughter, N., et al. “Final Report for CALTRANS.” **Intelligent Intermittent Spray System for Reduced Herbicide Control of Vegetation**. UC-Davis. Aug. 1994.

Smathers, W.M. Jr., et al., eds. Smith, M.R.; Wilkie, G.R. III. **Causal Factors and Possible Solutions to Reduce Highway Accidents Caused by White-Tailed Deer in South Carolina, Phase I.** Clemson University, Department of Agricultural and Applied Economics, Clemson, South Carolina South Carolina Department of Transportation, Columbia, South Carolina; Federal Highway Administration, Washington, DC. Sep. 2001. pp95.
[Deer/vehicle collisions represent external costs that result from the deer herd in South Carolina. In order to determine where these accidents occur and begin an economic analysis, a spatial analysis using Arc View Geographic Information System (GIS) software was performed to create comprehensive maps of collision sites in the state for the years 1995 and 1998. A sample of 12 of South Carolina's 46 counties was selected to represent the entire state. Statistical analysis determined the sample was representative of all 46 counties in terms of time of year and time of day of accident occurrence. Locational variables such as proximity to rivers and streams and proximity to towns were also included in this analysis. The most significant time of year for these accidents was found to be during the months of October, November, and December. The time of day

accounting for most collisions was from one hour before sunset until one hour after sunrise. A substantial percentage (42% on average for both years) of accidents occurred within 3 miles of a river or stream. The importance of proximity to towns varied between counties (from 1.9 to 43.5% of total accidents). Mitigation efforts reported in the literature include high fencing and road signs. High fencing was reported the most effective, also being the most expensive. Suggested techniques include management of roadside vegetation, reduced speed limits, education, and deer hunting. Hunting is potentially the most efficient of these measures because it involves reducing the deer herd.]

Smithson, Leland D. **Training: The Key to Technology Implementation,** American Association of State Highway and Transportation Officials (AASHTO). (No date.)

Stewart, A.T. **Roadside Management: Vegetation Control within the Highway Rights of Way.** Alberta Transportation. Aug. 1986. 52p.
[A thorough review of the benefits of roadside vegetation control and the methods of control was conducted. After determining that vegetation control is desirable, numerous roadside vegetation management approaches were analyzed. Additionally, a survey of the fifteen districts of Alberta Transportation and Utilities was undertaken to determine current departmental practices. In combining the literature search and survey information it is concluded that an integrated program of mechanical and chemical vegetation control is more suitable for implementation in Alberta. The combined management approach recommended provides a safe and efficient control program and it is the most economical means of achieving the desired level of vegetation control.]

Stringer, W.C. **Establishment and Management of Native Grasses and Forbs in Highway Corridors.** Clemson University, Crop and Soil Environmental Science Department, Clemson, South Carolina; South Carolina Department of Transportation, Columbia, South Carolina; Federal Highway Administration, Washington, DC. Sep. 2001. 0003-0209 pp53.
[Thousands of miles of roadside soils are never amended after original vegetation establishment. This project was designed to characterize the nutritional status of South Carolina's roadsides. The vegetation along the roadsides is also characterized. The I-26 corridor was selected to provide a transect across all the soil regions of the state. Soil pH was very near published native soil conditions (4.8 to 5.4). A few sites on the lower Coastal Plain near Charleston were approaching neutral pH, and these also exhibited very high levels of calcium. Phosphorus levels were low to very low over much of the state, except in the Charleston area. It is likely that the high pH, calcium and phosphorus near Charleston derive from the fill material which contains overburden from historic phosphate mining. Potassium was low in the Coastal Plain soils and moderate to high in the Piedmont soils, due to K -containing soil minerals there. The vegetation on mowed road margins and medians was largely introduced grasses seeded in the original revegetation programs. Bahiagrass was by far the most prevalent species. Less frequently mowed backslopes contained considerably more native species. Native grasses and forbs do not compete with close-growing grasses such as bahiagrass, bermudagrass, and tall fescue. Native species were common in areas

of backslope, especially where mowing operations have resulted in soil disturbance via scalping and tire slippage. The adaptation of native grasses and forbs to the poor soil fertility conditions is discussed. It is recommended that native species be planted or encouraged in many roadside areas, as they are perennial and have low maintenance requirements. They also have significant historical and cultural importance as well.]

Tan, Siew Ann, et al., eds. Fwa, T. F., Chai, K. C. **Drainage Considerations for Porous Asphalt Surface Course Design (04-2789)**. National University of Singapore. (No date.)
[The drainage performance of a porous asphalt surface course is dependent on drainage properties of the asphalt mixture, as well as the geometric design of the individual road sections. Hence, its minimum thickness requirement may vary from one section to another in a single road project due to changes in road geometric design, even though the same asphalt mixture is used for the surface course. However, the influence of road geometric properties, the effects of longitudinal gradient and cross slope on the thickness design of the surface course have not received the deserved attention. There are no readily available design tools that allow highway engineers to perform design check on thickness requirements effectively. This paper develops convenient plots to meet this need. A three-dimensional finite element program was employed to study the effects of cross and longitudinal slopes on the drainage performance of the porous asphalt surface course. The analysis shows that both the longitudinal gradient and the cross slope of road section affect significantly the drainage capacity of the porous surface course. A family of thickness requirement graphs have been prepared for easy application. These graphs are plotted as functions of design rainfall, thickness of surface course layer, width of pavement, and longitudinal and cross slopes.]

"Transportation Research Circular" **Maintenance Management 2003:** *Presentations from the 10th AASHTO–TRB Maintenance Management Conference.*

Tueller, P.T., et al., eds. Post, D.; Noonan, E. **Mapping Ecosystems Along Nevada Highways and the Development of Specifications for Vegetation Remediation.** University of Nevada, Reno, Department of Environmental and Resource Sciences, Reno, Nevada; Nevada Department of Transportation, Carson City, Nevada. 20 Sep. 2002. 0107-0207 pp61.
[This project inventories the major plant communities and general soil classification units along Nevada highways and recommends the best procedures and management practices for vegetation remediation based on the appropriate ecosystems and soil types. Vegetation and soils were mapped using Landsat thematic mapping data along a five-mile corridor for all Nevada state and federal highways. Soils data were extracted from information provided by the Natural Resources Conservation Service. The maps are presented by county. Revegetation protocols were described for eight general vegetation types associated with Nevada highways. The specifications include site analysis, species selection, site preparation and specific revegetation procedures. The seeding specifications include information on proposed species and species mixtures, fertilization, seeding method, supplemental irrigation and erosion control. Species selected for remediation purposes have been evaluated for drought tolerance, minimum annual rainfall needs, salt and alkali tolerance, seedling vigor, growth habit, suitable soil groups,

seeding rates, pure live seed, availability, and general costs for native seed sources. In addition, three specific site examples have been described in detail with specific reclamation steps. Monitoring procedures to evaluate the success of remediation are described. The report also presents an inventory of noxious and invasive weeds and discusses the hazard of possible wildfire along the highways.]

U.S. Dept. of Agriculture, **Glyphosate, Herbicide Information Profile**. Nov. 2000.

Varland, K.L., and Schaefer, P.J. "Roadside Management Trends in Minnesota 1973 to 1997." Federal Highway Administration, Washington, DC. Conference Title: International Conference on Wildlife Ecology and Transportation. Location: Fort Myers, Florida. Sponsored by: Florida Department of Transportation; U.S. Department of Transportation; U.S. Forest Service; and Defenders of Wildlife. 1998. pp214-228.
[Minnesota's Roadsides for Wildlife (RFW) Program was initiated in 1984 to (1) promote roadside habitat awareness, (2) reduce spring/summer roadside disturbance, and (3) improve quality of roadside habitat. Special roadside management surveys completed in 1973 and 1983 indicated that roadside disturbance was negatively impacting wildlife habitat on more than 40% of roadsides. Each August, since 1984, the RFW Program conducted a management survey that coincides with the Minnesota Department of Natural Resources (DNR) roadside wildlife counts to measure the Program's impacts and determine management trends. Roadside mowing dominated roadside disturbance. Disturbance has averaged a 19% decline impacting 42,450 ha since the beginning of the Program. A 1985 roadside mowing law has resulted in reduced roadside mowing. Weather is also a factor. Undisturbed roadside vegetation has remained relatively stable since 1987. The greatest reductions in roadside disturbance have occurred in east-central and west-central regions. The peak of mowing activity during summer has remained the same since 1984 with about 80% occurring during July 1-31. Other disturbance factors (lawns and agricultural encroachment) have increased in east-central, south-central, and west-central regions. Poor quality nesting cover remained relatively stable from 1992-97 and averaged about 16% of roadsides surveyed. Good quality cover increased from 25% to 45% and moderate quality cover declined during this period. A public relations approach to roadside management has brought about changes in legislation, mowing behavior, and greater participation by road authorities. Future Program emphasis will include integrated roadside vegetation management and increased use of native prairie vegetation.]

Washington State Department of Transportation. **Zone One Roadside Vegetation Management Implementation Task Force Study**. Jun. 1992.

Washington State Department of Transportation. **Value Engineering of Roadside Management, Zone One.** Team report, Apr. 1992.

Washington State Department of Transportation. **Roadside Vegetation Management Programmatic Environmental Impact Statement**. December, 1993.

Washington State Department of Transportation. **Guidelines for Implementation of a Modified Zone 1**. Draft. Apr. 1994.

Washington State Department of Transportation. **Roadside Classification Plan**. 1996.

Washington State Department of Transportation. **Integrated Vegetation Management for Roadsides**.1997.

Washington State Department of Transportation. **Supplement to Appendix B, Environmental Impact Statement 1993 Roadside Vegetation Management**. 2003.

Washington State Department of Transportation. **2, 4-D, Roadside Vegetation Management Herbicide Fact Sheet**. Jul. 2003.

Washington State Department of Transportation. **A Comparison of Roadside Maintenance Practices- Impacts of Herbicide Use on Cost and Results**. Dec. 2003

Washington State Department of Transportation. **Integrated Roadside Vegetation Management Plan – State Highways in Clallam County**. Jul. 2003.

Washington State Department of Transportation. **Whidbey Island Integrated Roadside Vegetation Management Plan**. WSDOT. 2003.

Washington State Department of Transportation. "SR20 Whidbey Island Roadside Restoration Strategies." **Value Engineering Study Report**. Northwest Region. Feb. 2005.

Washington State Department of Transportation. "WSDOT Zone 1 Survey Responses" from Area Maintenance managers. 2004.

Washington State Department of Transportation. Statewide Zone 1 Survey. Spreadsheet of compiled results. Sep. 2004.

Washington State Department of Transportation. **Implementing ESA Buffers for Diuron and 2,4-D**. WSDOT. Northwest Region, Area 5 Maintenance Office. 2004.

Washington State Department of Transportation, **Maintenance of Vegetation at the Pavement Edge, A survey of practices in Washington, British Columbia, California, Idaho, Iowa, Maryland, Minnesota, Montana, Oregon and Utah, DRAFT**. 2004.

Williams, K. **Environmental Stewardship in NYSDOT Highway Maintenance.** New York State Department of Transportation, Albany, NY; Federal Highway Administration, Washington, DC. Conference Title: International Conference on Ecology and Transportation. 2003 Proceedings. Location: Lake Placid, New York. Sponsored by: Federal Highway Administration, USDA Forest Service, Environmental Protection

Agency, New York State Department of Transportation, American Association of State Highway and Transportation Officials, Transportation Research Board, et al. 2003. pp5.
[The New York State Department of Transportation (NYSDOT) operates and maintains approximately 16,500 miles of highway that occupies approximately 1 percent of the state's land area. Because of to the tendency of the highway system to follow streams, coastlines and other natural landscape features, this 1% of land is located within, over and adjacent to many very sensitive and important environmental areas. Considering that NYSDOT, like most transportation departments, is now shifting its efforts more and more towards improving, operating and maintaining the existing transportation infrastructure, as opposed to building large-scale new alignment projects, the role of incorporating environmental improvements into maintenance and operational programs is increasing in importance. The project objective was to proactively reach out to internal and external partners to identify priorities and develop multi-agency strategies and projects that improve environmental conditions along NYSDOT's rights-of-way and roadsides. The approach required thorough internal teamwork involving many regional groups and external partnering with resource agencies and environmental organizations in order identify, develop and coordinate prioritized environmental stewardship projects. These "best practices" are then implemented during highway maintenance activities. NYSDOT has 11 regional offices with each region having a Landscape Architecture/Environmental Services unit located within the Regional Design Group. Although, located within the Design Group, these Units provide environmental services to all regional groups - including maintenance. In addition, in 2001, a senior environmental specialist (a.k.a. maintenance environmental coordinator or MEC) was assigned to each regional maintenance group to supplement existing programs by dedicating full-time effort coordinating environmental issues in the maintenance group. One aspect of this effort has been a focus on incorporating environmental right-of-way and roadside "Best Practices" into regional maintenance programs. Critical elements of this strategy include fostering internal teamwork within the region and developing partnerships with external groups. By using internal knowledge and resources and external expertise and assistance, the Department's organizational strengths can be efficiently and effectively managed to expand right-of-way roadside environmental stewardship programs. Examples of 2002 "best practices" to be discussed include: (1) control methods for invasive plants; (2) installation of water level control structures at chronic nuisance beaver locations; (3) installation of water quality improvement structures near drinking water supplies; (4) turtle mortality abatement efforts; (5) alternative mowing strategies to enhance grassland songbird nesting habitat; (6) establishment of living snow fences; (7) osprey nesting enhancements; (8) methods to reduce deer vehicle collisions; (9) migratory bird protection on bridges; (10) herbicide education programs; and (11) small petroleum spill abatement measures.]

Wood, T.M. **Herbicide Use in the Management of Roadside Vegetation, Western Oregon, 1999-2000: Effects on the Water Quality of Nearby Streams**. U.S. Geological Survey, Oregon District, Portland, Oregon; Federal Highway Administration, Washington, DC; Oregon Department of Transportation, Research Group, Salem, Oregon. Apr. 2001. 9902-0006 pp31.

[The Oregon Department of Transportation (ODOT) uses the herbicides Krovar (active ingredients diuron and bromacil), Oust (active ingredient sulfometuron-methyl) and Roundup (active ingredient glyphosate) to control roadside vegetation. The purpose of this study was to assess whether the use of these herbicides could contribute to the load of herbicides carried by Oregon streams. In spring of 1999, three test plots were constructed on a road shoulder near a crossing of Bull Creek, a small stream near Colton, Oregon, in the Willamette Valley. Simulated rainfall of 0.3 in/hr was applied to the experimental plots 1 day, 1 week, and 2 weeks after herbicide application. The simulated rainfall experiments yielded an upper limit concentration of 1 mg/L (milligrams per liter, or parts per million) glyphosate and diuron, and of a few hundred micrograms per liter (parts per billion) of sulfometuron-methyl in runoff from the roadside when rainfall was applied 24 hours after spraying. Concentrations in the ditch itself would be less under natural conditions because of dilution by drainage water from the entire contributing drainage area. The road shoulder was resprayed at the end of September, and data were collected from late October 1999 through early January 2000, during natural rainfall. Diuron concentrations in the direct runoff from the road shoulder ranged from 1 to 10 mcg/L micrograms per liter) throughout the 3-month sampling period; during the period, concentrations in the roadside ditch decreased from about 10 mcg/L in October to about 0.1 mcg/L in January, indicating progressive dilution of the roadside herbicide runoff during the fall/winter rainy season. No diuron was detected in Bull Creek downstream from the drainage ditch. A mass balance calculation confirmed that the load to Bull Creek from the drainage ditch was too low to result in detectable concentrations in the stream during October to January. Sulfometuron-methyl concentrations in runoff from the road shoulder ranged from 0.1 to 1 mcg/L throughout the 3-month sampling period, and in the drainage ditch decreased from about 1 mcg/L in October and November to about 0.2 mcg/L in January. It was never detected in Bull Creek. Bromacil concentrations were similar to those of diuron. Glyphosate was never detected in fall samples from the road shoulder, the drainage ditch, or the stream.]

Woods, D.L., et al., eds. Alcoz, S.; Smith, R.E.; Koppa, R.J. **A Maintenance Level of Service Evaluation Procedure for Texas. Final Report**. Texas Transportation Institute, Texas A&M University, College Station, Texas; Texas Department of Transportation, Office of Research and Technology Transfer, Austin, Texas. Dec. 1994. 9302-9408 pp144.

[The level of maintenance within the state of Texas varies to a substantial degree. Desirably the maintenance would be a reasonably uniform level across all the various essential components. The purpose of this project was to devise methods for objectively measuring the essential elements maximizing automated data collection techniques. The development team has reviewed the literature on maintenance evaluation. Three sources stand out: ROCOND 87 and ROCOND 90 from Australia, the Virginia Program, and the Florida Program. Each of these sources has helped shape the recommended evaluation procedure for Texas. The various maintenance elements were divided into seasons of the year to adapt to the time when that element would be critical. Those that are not time dependent were distributed to balance the data collection workload. Many continuous elements, such as vegetation, roadside drainage, etc., are scheduled for videotape data collection. Selected features will be collected visually by the data collection operator;

noxious weeds, pavement edge drop-off, and cross drainage structures are typical examples. A random site selection program has been prepared to obtain 0.15 km (0.1 mile) length sample sites. The evaluation program has been conceptually developed and has been fully field tested prior to full scale implementation.]

Yonge, David. **Contaminant detention in highway grass filter strips,** Washington State Department of Transportation, Olympia, Washington; [Springfield, Virginia: Available through the National Technical Information Service, 2000].

Young, Steve. "Final Report for CALTRANS." **Exploring Alternative Methods for Vegetation Control and Maintenance Along Roadsides**. UC-Hopland Research and Extension Center. Feb. 2003.

SECTION IV. CONFERENCE PRESENTATIONS

Glanville, T.D., et al., eds. Richard, T.L., and Persyn, R.A. Impacts of Compost Application on Highway Construction Sites in Iowa. ASAE Meeting Paper No. 01-012076 presented at **ASAE International Meeting**, Sacramento, California. Jul. 30-Aug. 1. 2001.

Harper-Lore, B.L. **Roadside Review of Vegetation Problems, Policy, and Applied Research.** CA: New York State Department of Transportation, Albany, New York; Federal Highway Administration, Washington, DC. 2003. SO: Conference Title: International Conference on Ecology and Transportation. 2003 Proceedings. Location: Lake Placid, New York. Sponsored by: Federal Highway Administration, USDA Forest Service, Environmental Protection Agency, New York State Department of Transportation, American Association of State Highway and Transportation Officials, Transportation Research Board, et al.
[It is only in recent years that maintenance and landscape crews in transportation began to think of themselves as land managers, with some historic exception. Combining interstate and state highway rights-of-way, they care for some 12 million acres of land across the nation. Because their highway corridors slice through your lands, neighbors need to know what they do and why they do it. Together roadside managers are willing to partner with adjacent landowners and agencies to implement current best management practices (BMPs). Some BMPs address the age-old questions of safety, construction costs, and environmental impacts follow, along with suggestions for future change.]

Persyn, R.A., et al., eds. Glanville, T.D., and Richard, T.L. Evaluation of Soil Erosion and Soil Erodibility Factors for Composted Organics on Highway Right-of-Ways. ASAE Meeting Paper No. 022081 presented at **ASAE International Meeting**, Chicago, Illinois. Jul. 28 – Jul. 31. 2002.

Radhakrishnan, Jayakumar, et al., eds. Teasdale, John; Coffman, Charles. "Vinegar As a Potential Herbicide for Organic Agriculture." **Proceedings of Northeastern Weed Science Society.** Jan. 7. 2002

[Vinegar (acetic acid) is registered as a herbicide for weed control in concrete pavements in Sweden (David Hansson, personal communication). However, there is no scientific literature on the use of vinegar for agricultural purposes available. The objective of this research was to study the efficacy of vinegar as a potential candidate for weed control in organic farming situations. Replicated greenhouse experiments were conducted during Spring and Fall 2001 with five weed species. The plants were hand-sprayed with 0.0, 5.0, 10.5, 15.3 and 20.2 percent vinegar obtained from Heinz Corporation to obtain a uniform wetting of all foliage. The results of the three weekly visual ratings of the percent indicated that the effectiveness of the vinegar to kill weeds was dependent on the concentration and the plant growth stage. Lower concentrations of 5 and 10 percent were more effective in killing the weeds during the early stages while at later stages they were not as effective as the 15 and 20 percent concentrations. Vinegar provided 95-100 per cent kill at all growth stages of the weeds studied at 15 and 20 % concentrations. Canada thistle was the most susceptible species with 100 percent kill of top growth with 5 % vinegar. However, there was some regrowth from the roots of plants of all age groups. Vinegar has a potential to be used as an inexpensive herbicide for spot treatment of organic farms.]

Richard, T.L., et al., eds. Persyn, R.A., and Glanville, T.D. Cover Crop Production and Weed Control on Highway Right-of-Ways Using Composted Organics. ASAE Paper No. 022051 presented at **ASAE International Meeting**, Chicago, Illinois. July 28 - July 31. 2002.

Snodgrass, W.J., et al., eds. Cain, N.P.; Perchanok, M.S. “Innovative Methods for Integrating the Design of Highway Rights-of-Way to Minimize Life Cycle Costs.” Conference Title: XIIIth World Meeting of the International Road Federation. Location: Toronto, Canada. Sponsored by: International Road Federation. 1997. **International Road Federation**, Washington, DC.
[Highway interactions with the surrounding natural environment have consequences for highway operating authorities, highway users, adjacent property owners, and the public agencies responsible for soil, vegetation and water quality. Consequences to the highway are primarily through increased maintenance costs due to deicing salt application and increased accident risk due to blowing snow, slippery road surfaces, obscured sight lines and animal collisions. Effects outside the highway are caused by substances such as salt, hydrocarbons and heavy metals. Both effects to the highway and effects caused by the highway can be controlled through design features within the highway right-of-way. This paper presents concepts for developing an integrated roadside for one Ontario site. These concepts are presently being applied to and tested for several Ontario sites in terms of the benefits, direct and indirect cost savings, safety and maintenance as well as design implications and environmental tradeoff. The benefits and tradeoffs are site specific.]

Webb, G.R. “Asset Management for Long Term Road Maintenance Contracts.” **Institute of Public Works Engineering Australia** (IPWEA), National Conference. Hobart, Tasmania, Australia, 2003. 10p.
[Emoleum Maintenance is responsible for the delivery of road and road corridor maintenance of Tasmania's southern road network. The diversity of activities involved in

the delivery of the contract ranges from snow clearing in alpine environments to pavement repair and resurfacing operations on busy urban highways. It includes land management activities such as roadside mowing, landscape maintenance, weed control, protection of threatened species amongst other maintenance activities. The successful fulfillment of the contract is dependant upon establishing and maintaining integrated asset management systems that effectively translate data into information that can be communicated, understood and acted upon. This paper discusses some of the elements of the asset management systems employed in the delivery of maintenance and rehabilitation services in the management of Tasmania's southern road network on behalf of all road users.]

SECTION V. NON-PEER REVIEWED LITERATURE

"Arkansas Roadside Crews Operate Safety." **Better Roads.** Oct. 1998. 68(10) pp24-25
[This article describes how Little Rock, Arkansas Highway and Transportation Department officials solved mowing problems along Interstate 630. A major portion of the highway runs through a downtown historic district known as the Quapaw Quarter, earning its roadsides designation as a park area. This means no broadcast spraying is used for vegetation control. The slopes were dangerously steep, with potential for accidents and injuries due to the amount of mowing. A Keystone Compac Segmental Retaining Wall was constructed alongside I630, and spraying around signs and cracks in the roadways above is handled with spot treatment of herbicides. The redefined slopes have made maintenance much safer for mowing crews.]

Austroads. **Use of Recycled Materials and the Management of Roadside Vegetation on Low Trafficked Roads.** 2000. 59p.
[This report provides the results of two separate reviews into practices relating to low trafficked roads: namely, the use of recycled materials and the management of roadside vegetation. This guide covers practices related to the recycling of materials by Councils in all States and aims to establish best practice. The review into roadside vegetation initially targeted the control of roadside vegetation where 'control' represented a reactive approach to vegetation maintenance. The scope was subsequently broadened to include a more proactive and strategic approach to roadside vegetation management. The purpose of this report is to establish and disseminate information on environmentally acceptable management of vegetation on the roadsides of low trafficked roads. Included are guidelines for the management of roadside vegetation and council responses to the developed questionnaire. Both reviews involved the research of literature of current practice, both in Australia and overseas, and the assessment of current local government practice from a limited response to a survey to all Councils. Urban and rural Councils in each State, State Road Authorities, the Institute of Municipal Engineers Australia, suppliers of recycling plant and materials, and the Roadside Environmental Committees in Victoria, New South Wales and Western Australia were all consulted in the course of the project.]

Caylor, P. “Herbicides Help Illinois DOT Control Roadside Weeds.” **American City and County.** Mar. 1998. 113(3) pp17-18.
[Mowing is the standard method for eliminating weeds and woody brush from highway roadsides. The Illinois Department of Transportation (IDOT), however, has found herbicides to be a more effective solution. In 1997, IDOT began using Garlon 3A to take care of weeds and brush such as Canada thistle, musk thistle, teasel, willow, box elder, elm, and black locust, without disturbing sensitive ornamentals. Garlon 3A is not "soil active," meaning it does not seep into the soil, so the ornamentals do not absorb it. In areas without ornamentals, IDOT uses Tordon 101M. Spraying herbicides costs about $15 per acre, while mowing costs approximately $30 per acre. Moreover, the results have been better because herbicides are designed to be absorbed by the plant, thus killing it. Spraying is also safer for IDOT workers, since it does not have to be repeated like mowing and therefore reduces workers exposure to high-volume, high-speed traffic.]

Cedergren, H. **Drainage of Highways and Airfield Pavements**. New York: John Wiley and Sons, Inc., 1974.

Cox, Caroline. “RoundUp® “Inert” Surfactant is Poisonous.” **Journal of Pesticide Reform**. Vol. 8, No. 1, Spring 1988.
[Surfactant polyoxethyleneamine (POEA) three times more toxic than glyphosate and belongs to a class of surfactants, which includes a spermicidal agent.]

“Crop Choice News.” Sep. 25. 2002. **Rachel’s Environment and Health News**. issue 751. Sep. 5. 2002.

Daar, Sheila. “Managing Roadside Vegetation without Herbicides.” **The IPM *(pest management)* Practitioner**. Jul. 2001.

Daar, Sheila. “Vegetation Management on Rights-of-Way: An Ecological Approach.” **The IPM *(pest management)* Practitioner**. Feb. 1992.

“Data Roundup Shows Pesticide Use Is Down.” **The Pest Monitor**. City of Seattle Pesticide Reduction Program; Office of Sustainability and Environment. May. 2002.

“Discussion Letter,” Whidbey/Camano Island No Spray Coalition, Dec. 2003

Eco-Mulch-Mat, product literature.
www.greenbeltconsulting.com
[Natural fiber mat for weed control lasting 2-5 years after establishment.]

Elmore, M. “Roadside Maintenance Challenges in a Shrinking Economy.” **APWA Reporter.** Jul. 2003. 70(7) pp28-29
[This article relates how city officials in Bend, Oregon used cooperative partnerships with different agencies in order to provide effective roadside maintenance when faced with budget constraints. It describes how an "Adopt-A-Road" program, the purchase of a multi- purpose tractor unit, creating an effective communication program bringing citizen

groups together with city officials, and establishing a neighborhood associations program enabled the city to its maintenance obligations in an economically-challenged environment.]

Game Lands 33: 50-Year Research Project Yields Fascinating Data Collection. Asplundh Tree Expert Co., 2003.

Gregorski, T. "More Than Meets the Eye: NRVMA's 2002 Roadside Excellence Award Winners, Exhibit All-Around Strong Programs." **Roads and Bridges.** May. 2003. 41(5) pp48-51 (3 Photo.)
[This article describes the 2002 awards given by the National Roadside Vegetation Management Association (NRVMA) to organizations that excel in roadside vegetation management. The South Carolina Department of Transportation (SCDOT) won in the state Department of Transportation category for its top-level management commitment to a roadside vegetation management program. Highlights of SCDOT's Integrated Roadside Management (IRVM) program include a full-time IRVM coordinator, an annual agency IRVM plan, a monthly vegetation management newsletter for SCDOT employees, an intranet website developed for vegetation management issues, and the planting and maintenance of 1,100 acres of cultivated wildflowers on SCDOT roadsides. John Kabus of the Shawnee County Noxious Weed Department of Topeka, Kansas received an award for his vegetation management program, his work with the state legislature, local land owners and citizens, as well as for his public relations efforts that have brought more attention to noxious weed-related issues. Terri Rogers, instructor of the Natural Resources Management Program at Hawkeye Community College in Waterloo, Iowa, was selected for having developed what may be the only degree program on roadside vegetation management in the U.S., as well as for her work in encouraging and sponsoring students to become active in roadside vegetation management activities.]

Heidger, Clemens, and Kurkowski, Harald. "Pavement Bases with Vegetation-Oriented Properties." **Strassen und Tiefbau**. 2003.

Marum, E. "GPS Helps Manage Roadside Vegetation." **Roads and Bridges.** 2000/05. 38(5) pp36-38.
[The Integrated Roadside Vegetation Management (IRVM) is Iowa's long-term approach to reintroduce native grasses and wildflowers to roadsides creating beautiful passages capable of resisting weeds and soil erosion while using little or no maintenance. A few years ago, Clinton County, Iowa, put a three -product chemical injection system on their spray truck to save time and money. Road crews went from treating 20 mi of roadway to 50 mi each day, and in nearly every case they were doing a better job. The next breakthrough came when the deputy director of the county conservation board was tipped off to a new Roadway Management System that records the placement of multiple herbicides to an onboard computer connected to a differentially corrected global positioning system (GPS) receiver. With a system like this, the county could integrate data from years of mapping and spray areas where weeds proliferated. At the same time, crews could carefully avoid sensitive areas they had nurtured over the past decade. A few seasons of use, good empirical data logging of what goes where, and careful management

of that data and visual confirmation will let Clinton County know for certain. However, if it works, Iowa will benefit with more beautiful roadsides managed more effectively by the same number of people using less intrusive methods of management. A sidebar provides details on the Mid-Tech's Roadway Management System.]

McIntyre, W. "Let the Drain Take the Strain." **Highways.** Vol. 62, no 7, p.34. 1994.
[The goal towards better drainage of road surface necessitates a general performance specification because today's ditches and open channels do not meet present needs. The hydraulic performance of existing drainage systems deteriorates with concrete degradation or vegetation growth. Aside from requiring large maintenance, they fall prey to the attendant pollution from petrol, oil, and other road pollutants. That ungated or open channels trap such debris further complicates the problem. Given properly formulated product performance specifications and design standards, which must include hydraulic capacity, modern channel drainage systems will surely improve the safety and economy of roads.]

National Resource Defense Council. **Pesticide Use, The Green Gate: NDRC's Environmental Guide to the San Francisco Bay Area**. 2004.

"California Communities Wage New King of War on Roadside Weeds." **Public Works**, Dec. 2002.133(13) pp22-25.
[The State of California is leading the way toward new policies in roadside weed management that do not rely as heavily on mowing and spraying, because of environmental concerns and budget and safety constraints. The California Department of Transportation (Caltrans) is seeking to reduce herbicide spraying by 80 percent by the year 2012 and has already met an earlier goal of cutting herbicides by 50 percent from 1992 levels. New machines make herbicide application more precise, reducing waste, exposure by workers and runoff. They use sensors and robotics to fine tune spraying. Another tactic involves selective planting of native plants, especially perennial native grasses. One county was able to eliminate herbicides altogether after a couple of years of plant restoration. Goats are used for certain plants, especially before they bloom. It requires working closely with the goatherd to target use. In addition, Caltrans has begun a multi-year project along Highway 1 in Santa Cruz using weed control mats and a liquid soil sealer.]

"Roadside vegetation managers keep track with GIS/GPS." **Public Works**, Jan. 2001. 132(1) pp56-58.
[Roadside vegetation managers are finding that using GIS/GPS-based maps to monitor their programs can cut weed control costs by increasing the effectiveness of weed treatments and reducing waste and payouts for liability claims alleging misapplication of herbicides. The GIS/GPS maps' accuracy to within a few feet reduce liability claims because they more clearly document where herbicides have been used and enable more precise application of herbicides. By informing nearby landowners of weed infestations by mailing out GIS/GPS-based maps, managers saw an increase in the number of landowners practicing weed control on their parcels. The maps also help managers to better tailor budgets and explain them to policymakers and elected officials.]

"Sedgwick County upgrades weed control." **Better Roads**. Sep. 1997. 67(9) pp21-22
[Innovative techniques and improved results with weed control made Sedgwick County in Wichita, Kansas, a winner in last year's National Roadside Excellence contest sponsored by NRVMA. The department has as its objectives: Noxious weed control; roadside safety by assuring adequate sight distance and clear shoulder areas for emergency traffic; reducing roadbed maintenance costs by eliminating vegetation-caused drainage problems; eliminating brush and health-related weeds; and providing a pleasing roadside appearance.]

Sherman, F. "Roadside Vegetation Management: Herbicides and Beyond." **Transportation Builder**. Apr. 1995. 7(4) pp18-20.
[Chemical treatment of roadside vegetation can be an effective, but unpopular choice in vegetation management. This article describes various approaches to roadside vegetation control that go beyond herbicides. Mowing and planting are favored by the public, and occasionally, herbicides and growth retardants can be used in spot spraying. Budget constraints can dictate the amount of work that can be done overall; consequently, a prevention approach, such as plantings that require minimal attention, may be an appropriate solution. The integration of spraying, manual labor, and prevention can culminate in a practical plan for weed control.]

"Some Health Consequences of RoundUp® Poisoning." **Ecologist**. Vol. 28. No 5. Jun. 1999.

Steingraber, Sandra. **Living downstream: An ecologist looks at cancer and the environment**. Perseus, Reading, Massachusetts. 1997.

Stidger, R.W. "Federal Guide Moves Online," **Better Roads**. Feb. 2002. 72(2) pp22-23.
[A Federal Highway Administration guide, "Roadside use of native plants," is now being offered online. It offers guidance for managing vegetation on national highways (integrated roadside vegetation management) and emphasizes information on native plants and revegetation processes including the control of invasive species. The guide can be found on the Web at http://www.fhwa.dot.gov/environment/handbook.htm.]

"Survey Results: How DOTs Control Vegetation." **Better Roads**. Sep. 1997. 67(9) pp19-20.
[Vegetation managers and maintenance supervisors were surveyed by Better Roads' editors as to their chemical and mechanical mowing practices, equipment, and where the future of vegetation management is headed. Survey responses indicate fewer chemicals are being used, more labor is being outsourced, and more native plant species are being used to naturalize roadsides. Chemical companies are providing more environmentally friendly herbicides to meet new changes in regulations. A number of the top DOT chemical choices are Group E -- said to be virtually non-toxic -- compounds, having the safest EPA designation.]

Walker, C., and MacDonald, M. "Designer Drain." **Highways.** Vol. 62, no 7, p.19-20. 1994.

[The design of highway drainages is increasingly being affected by Today's highway drainages exhibit preference to designs having minimal effect on the surrounding water regime. While the major functions of highway drainage remain unchanged, disposal of surface water now depends on the area and type of surface drained and the relevant intensity of rainfall. Provisions are now being made to help eliminate solids and other pollutants of the floodwater to protect collecting watercourses and aquifers. A favorable solution is offered by biofiltration or the use of vegetation to 'filter' dissolved pollutants through mineral uptake. Particular attention is also given to keeping drainages from disturbing the natural range of fishing areas or wildlife sanctuaries.]

Walvatne, Paul. "Minnesota DOT Integrated Vegetation Management." A slide show for WSDOT training. Mar. 2004.

WeedEnder brochure. "Vegetation control mat." U-teck, Inc. (circa 2004)

Young, Steve. "Exploring alternative methods for vegetation control and maintenance along roadsides." **CalEPPC News**. UC-Davis, Winter 2002.

Zeyher, A. "In the Weeds: NRVMA Rewards Those Who Can Handle Being Off the Fairway." **Roads and Bridges.** May. 2002. 40(5) pp42-45.
[This article presents the winners of the 2001 awards from the National Roadside Vegetation Management Association for excellence. They include the city of Duluth, MN, the Florida DOT, Great Bend, KS, and the company of Becker Underwood in Ames, IO. Duluth roadsides include 40 acres of gardens along the Lake Superior shore, which are maintained with a minimum of chemicals. Florida has incorporated highway beautification into all its highway construction plans at the earliest design stages and funds beautification in proportion to construction. The noxious weed department of Barton County, home to Great Bend, has learned to rely on native grasses to reduce the need for mowing and deprive the four most invasive strangers of growing space. Becker Underwood's color sprays let vegetation managers see where applications have been made. They break down in light and water.]

SECTION VI. REFERENCES PROVIDED IN INTERVIEWS, NOT LOCATED

Albrick, William. **The Albrick Papers.** (3 vols.) (No date.)

Biosol: soil augmentation product by Rocky Mountain Bioproducts. Dried sterilized fungal and biomasses.

Debinski, Diane M, and Hendrix**,** Stephen D. "Sustaining Pollinator Diversity in a Fragmented Landscape: The Role of Roadsides and Railroad Right-Of-Ways: A Summary of Accepted Proposal to the Iowa Department of Transportation." (No date.)

Don't Plant A Pest! Suggested alternatives for invasive garden plants of the greater San Francisco Bay Area. California Invasive Plant Council Nursery Sustainability Program. (No date.)

"Dr Abrahamson's study of wetlands and herbicide contamination" (No date.)

Dunlap, David. "Pilot Study of the Influence of Vegetation and Other Factors on Pavement Condition." **Transportation Research Record**. 1326.

Hall, Kathleen T., et al., ed. Correa, Carlos E. "Effects of Subsurface Drainage on Performance of Asphalt and Concrete Pavements**." NCHRP Report 499.** Protech Engineering, Mundelein, Illinois. (No date.)

Jha, Manoj K., and Schultz, Leonard. "Development of an Integrated Highway Maintenance Management System." **The Maryland Experience**. (No date.)

Jackson, Laura L. "Adding Wildflower Diversity To Species-Poor Grasslands: Effects Of Mowing Frequency." (No date.)

"Materials that help control corrosion." **Better Roads.** 1992. (author, volume and month missing)

Middleton, L., and King, M. "A Natural Choice" **Public Roads.** (No date.)
[Controlling erosion and reestablishing vegetation are key components in most road and highway construction or rehabilitation projects. Roadside embankments, shoulders, medians, and other nonpaved surfaces can be vulnerable to the elements, leading to excessive runoff, rutting, and damaged aesthetics. Conventional methods to prevent these conditions include hydroseeding and root reinforcement systems. In recent years, an alternative erosion control mechanism—compost—has been gaining in popularity.]

Moloney, Kirk A., et al. Impact of Plant Community Composition on the Spread of the Invasive Plant Species Crown Vetch (Proposal). Iowa State University. (No date.)

National Pesticide Stewardship Alliance. "Applications of Integrated Pest Management to Electric Utility Rights-of-Way Vegetation Management in New York State." **Environmental Energy Alliance of New York, Land Use Subcommittee Committee Position Paper.** (No date.)

Transportation Research Board. "Appendix Ss: Hydraulic Design, Maintenance, and Construction Details of Subsurface Drainage Systems**." Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures**. National Research Council. Submitted by Ara, Inc., Eres Division. (No date.)

USDOT and Federal Highway Administration. **The Nature of Roadsides and the Tools to Work with It**. (No date.)

Walters, Charles. **Weed Control without Poisons.** (No date.)

APPENDIX B
WORKING GROUP BRAINSTORMING LISTS

Table B-1. Decision factors suggested by the Working Group in a "brainstorming" session at the outset of work on the literature review.

Honoring critical areas ordinances
Super elevation of road surface/drainage consequences
Sedimentation
Human health
Function of Native plant communities in Zones 2 and 3
Pavement design
Hydroplaning
Scenic beauty
Pavement edge drop-off
Quality of asphalt/materials
New construction/re-design
Pedestrian safety
Bicyclists
Shoulder width
Structural integrity
Streams and wetlands
Rural vs. suburban
Construction costs
Employee hour requirements
Volunteer vegetation management
Environmentally sensitive areas
Statutory IPM
Treasured community sites
Utility/other Right of Ways
Sub-surface drainage of pavement
Groundwater recharge areas
Condition of soil – biological and physical
Offsite influences
Transition from Zone 1 to Zone 2
Diking at pavement edge-removal of buildup (hazardous)
Horizontal/vertical alignment
Fire starts
Traffic volume
Erosion
Salmon and endangered species
Noxious weeds
Sight distance
Wildlife, deer, otters, etc.
Presence of hardware, guardrails
Stormwater ponding
Stormwater quality and quantity run-off
Debris, gravel on road, garbage, etc.
Hardware life, posts, metal
Traffic disruption
Driver safety
Worker safety
Community concerns, perspectives
Other pollutants, oil, etc.
Curbs on shoulders
Microclimates
Protected and rare plant species
Traffic speed
Maintenance cost
Pavement life
Privatization of work activities
Volunteer litter pick-up (Adopt of Highway)
Roadside foraging
School bus activities
Curves, hills, intersections
Extra-sensitive human sites: hospitals, schools, churches
Laws and politics
Railroads
Topography
Drinking well locations
Sole source aquifers
Historic maintenance activities
Soil type
Sun or shade
Identification of edge
Presence of invasive plants – grow through the edge of paving
Aesthetics
Disposing of pavement edge material that accumulates
Surface water drainage connections

Table B-2. Alternative practices suggested by the Working Group.

Hot water
Radiant heat
Seeding – broadcast or hydrocast
Weed fabric/mats
Appropriate mowing
Redesigning areas:
  -paving
  -eliminate guardrails
  -slope
  -restore native plant communities
  -pavement edge design
  -curb Zone 1
Growth regulators
Fertilizing
Weed whacking, pulling, manual, hand removal
Organic pesticides, pre-emergents
Asphalt treated base construction
Do nothing, no action
Compost tea
Compost
Bump mowers
Enable scheduled maintenance
Training: plant identification, integrated vegetation management (IVM), etc.
Cut thistles before they go to seed
Monitoring
Steam
Foam
Vinegar
Soil remediation
Mulch
Blading/grading
Slope change
Soil binders
Bio-controls (goats)
Non-residual herbicides
Promote appropriate vegetation
Curbing
Tiger Claw – cultivation/tilling
Minimize WSDOT maintenance
Appropriate size mowers/equipment
Mulch under guardrails – comparative study of mulches
Preventive maintenance – get knotweed early

APPENDIX C
PROJECT PARTICIPANTS

Project Management		
Dave McCormick	NW Region Maintenance Engineer	Washington State DOT
Ray Willard	Roadside Maintenance Program Manager	Washington State DOT

Principal Investigators		
Kristina Hill (lead)	Associate Professor	UW, Dept. of Landscape Architecture
Richard Horner	Research Associate Professor	UW, Dept. of Landscape Architecture
Jacob Millard	Graduate Student	UW, Dept. of Landscape Architecture

Working Group Members		
Karl Arne	Pesticide Expert	US EPA, Region 10
Bob Berger	Landscape Architect	Roadside Vegetation Management Consultant
Jay Davis	Environmental Toxicologist	NOAA Fisheries
Lee Dorigan	Health and Environmental Inspector	King County Environmental Health Dept.
Heather Hansen	Executive Director	Washington Friends of Farms and Forests
Josey Paul	Local Coalition Rep.	Clallam County No Spray Coalition
Roy Scalf	Operations Manager	Snohomish County Public Works
Angela Storey	Pesticide Organizer	Washington Toxics Coalition
Jack Taylor	Maintenance Superintendent	Island County Public Works
Mark Wahl	Local Coalition Rep.	Whidbey Island No Spray/Whidbey Environment Action Network

Technical Review Committee Members		
Bruce Alber	Vegetation Management Sales Rep.	Wilbur-Ellis
Jim Andersen	Roadside Maintenance Supervisor	Washington State DOT
Sally Anderson	NW Region Landscape Architect	Washington State DOT
Bob Barnes	Olympic Region Landscape Architect	Washington State DOT
Rico Baroga	Maintenance Policy Manager	Washington State DOT
Jim Bjorgan	Roadside Maintenance Supervisor	King County Dept. of Transportation
Randy Bracket	Project Design Engineer	Island County Public Works
Susan Buis	Horticulturist	Washington State DOT

Jay Cammermeyer	Hydraulic Engineer/Stormwater Specialist	Washington State DOT
Dan Corlett	Southwest Region Landscape Architect	Washington State DOT
Ted Dempsey	Maintenance Superintendent	Washington State DOT
Jim Eastman	Assistant State Design Engineer (Roadside)	Washington State DOT
Marriane Edain	Local Coalition Rep.	Whidbey Environmental Action Network
Kathleen Emmett	Water Quality Expert	Washington State Department of Ecology, Water Quality Program
Paul Figueroa	Pesticide Compliance Manager	Washington State Dept. of Agriculture, Pesticide Compliance
Theresa Gandhi	Local Coalition Rep.	Whidbey Chemically Injured Network
Jack Hardy	Vegetation Management Sales Rep.	Monsanto
Mark Maurer	Roadside and Site Development Program Manager	Washington State DOT
Lane McCallistor	Roadside Maintenance Supervisor	Thurston County Public Works
Steve McGonigal	Executive Director	Washington State Noxious Weed Control Board
Elliot Menashe	Restoration Consultant	Greenbelt Consulting
Ed Molash	Water Quality Specialist	Washington State DOT
James Morin	Eastern Wash. Roadside Maintenance Program Manager	Washington State DOT
Barbara Morrissey	Pesticide Toxicologist	Washington State Dept. of Health, Pesticide Program
Ron Morton	Maintenance Superintendent	Washington State DOT
Pat Moylan	NW Region Assistant Maintenance Engineer	Washington State DOT
Lisa Murdock	Public Information Officer (Maintenance and Operations)	Washington State DOT
Alex Nguyen	Hydraulic Engineer	Washington State DOT
Norm Payton	Stormwater Management Coordinator for Maintenance	Washington State DOT
Linda Pierce	State Pavement Engineer	Washington State DOT
Kent Pittard	Vegetation Management Sales Rep.	Dupont
Tom Root	Maintenance Operations Manager	Washington State DOT
Erika Schreder	Staff Scientist	Washington Toxics Coalition
Mark Shelton	Roadside Maintenance Supervisor	Grays Harbor County Public Works
Bruce Smith	Environmental Policy Specialist	Washington State DOT
Mike Stephens	Stormwater Management Coordinator for Env. and Design	Washington State DOT
Duke Stryker	Roadside Maintenance Specialists	Washington State DOT
Frank Treese	Maintenance Superintendent	Washington State DOT
Richard Tveten	Stormwater Management	Washington State DOT
Ed Winkley	Olympic Region Assistant Landscape Architect	Washington State DOT
Matt Witecki	State Hydraulic Engineer	Washington State DOT

APPENDIX D.
WORKSHEETS FOR FIELD OBSERVATION OF VEGETATION MANAGEMENT PROBLEM AREAS (PART I) AND TEST AREAS (PART II)

PART I. INSTRUCTIONS FOR OBSERVATIONS OF ROADSIDE VEGETATION IN RELATION TO ROAD OPERATION AND MAINTENANCE PROBLEMS

Note: The term "pavement edge" means a strip parallel to the roadway extending approximately 1-2 meters from the pavement. WSDOT has traditionally referred to a pavement edge strip kept bare of vegetation as pavement edge.

Observe areas both with and without adequate drainage from the pavement and record the following information about pavement edge on the **Drainage Problems Recording Sheet** (take measurements as necessary to provide accurate information):

(a) Location (route/mile post)
(b) Whether or not the location has a drainage problem
(c) Vegetation types present
(d) Overall vegetation cover (rate from 1 [little or no cover] to 5 [fully covered])
(e) Range in vegetation height
(f) Soil conditions (rate as coarse, medium texture, fine)
(g) Type and amount of debris accumulation at edge between pavement and pavement edge and in pavement edge
(h) Vertical drop from shoulder pavement to pavement edge soil surface
(i) Pavement edge slope (Note: A crude estimate of slope can be made by extending a level from the shoulder edge and measuring the vertical distance between the level and the soil surface. Slope as a % is then the vertical distance divided by the length of the level times 100.)

Observe areas both with and without fire start problems and record the following information about pavement edge on the **Fire Starts Recording Sheet** (take measurements as necessary to provide accurate information):

(a) Location (route/mile post)
(b) Whether or not the location has a fire start problem
(c) Cause of fire(s) (burning material, vehicle fire)
(d) Vegetation types present
(e) Overall vegetation cover (rate from 1 [little or no cover] to 5 [fully covered])
(f) Range in vegetation height
(g) Type and amount of debris accumulation in pavement edge
(h) Distance from the edge of the traveled lane to pavement edge
(i) Any barrier to prevent vehicle entrance to pavement edge

Observe areas both with and without a relatively large number of wildlife road kills and record the following information on the **Wildlife Road Kills Recording Sheet** (take measurements as necessary to provide accurate information):

(a) Location (route/mile post)
(b) Whether or not the location has a road kill problem
(c) Distance from the edge of the traveled lane to pavement edge
(d) Vegetation types present in pavement edge
(e) Overall pavement edge vegetation cover (rate from 1 [little or no cover] to 5 [fully covered])
(f) Range in pavement edge vegetation height
(g) Vegetation types present beyond pavement edge (Zones 2 and 3 and outside right of way if not fenced
(h) Overall vegetation cover beyond pavement edge (rate from 1 [little or no cover] to 5 [fully covered])
(i) Range in vegetation height beyond pavement edge

Observe structural elements (guard rails, utility boxes, sign posts, bridge approaches, light standards) in pavement edge that both have and have not experienced elevated rates of deterioration and record the following information on the **Structural Deterioration Recording Sheet** (take measurements as necessary to provide accurate information):

(a) Location (route/mile post)
(b) Structural element(s)
(c) Whether or not the location has a structural deterioration problem
(d) Material of construction of the structural element
(e) Vegetation types present immediately adjacent to the structure
(f) Overall vegetation cover immediately adjacent to the structure (rate from 1 [little or no cover] to 5 [fully covered])
(g) Range in vegetation height immediately adjacent to the structure
(h) Vegetation types present in the vicinity but not immediately adjacent to the structure
(i) Overall vegetation cover in the vicinity but not immediately adjacent to the structure (rate from 1 [little or no cover] to 5 [fully covered])
(j) Range in vegetation height in the vicinity but not immediately adjacent to the structure

DRAINAGE PROBLEMS RECORDING SHEET

(a) Location	(b) Problem?	(c) Veg. Types	(d) Veg. Cover	(e) Veg. Height	(f) Soil	(g) Debris	(h) Vert. Drop	(i) Slope

FIRE STARTS RECORDING SHEET

(a) Location	(b) Problem?	(c) Cause(s)	(d) Veg. Types	(e) Veg. Cover	(f) Veg. Height	(g) Debris	(h) Distance	(i) Barrier(s)

WILDLIFE ROAD KILLS RECORDING SHEET

(a) Location	(b) Problem?	(c) Distance	(d) Pavement Edge Veg. Types	(e) Pavement Edge Veg. Cover	(f) Pavement Edge Veg. Height	(g) Veg. Types Beyond Pavement Edge	(h) Veg. Cover Beyond Pavement Edge	(i) Veg. Height Beyond Pavement Edge

STRUCTURAL DETERIORATION RECORDING SHEET

(a) Location	(b) Structure	(c) Problem?	(d) Material	(e) Adjacent Veg. Types	(f) Adjacent Veg. Cover	(g) Adjacent Veg. Height	(h) Vicinity Veg. Types	(i) Vicinity Veg. Cover	(j) Vicinity Veg. Height

PART II. RECORDING SHEET FOR OBSERVATIONS OF ROADSIDE VEGETATION MANAGEMENT TRIALS

1. Location (route/mile post):

2. Type of trial:

3. Setting of trial:

   (a) Directional location (east, west, north, or south side of road)

   (b) Is the trial location shaded? If so, describe how heavily and how extensive during the day.

   (c) Number and widths of traffic lanes

   (d) Number of lanes draining to the trial location

   (e) Adjacent shoulder width and material

   (f) Does adjacent shoulder drain to the trial area?
   Does the opposite shoulder?

   (g) Is there a median? If so, what is its width?
   Does it drain to the trial location?

   (h) Approximate average daily traffic

   (i) Describe traffic composition, especially if vehicles that drop debris are prominent.

4. Design of trial:

   (a) Are trial plots replicated two or more times? If so, give the number of replications.

   (b) Area covered by each replication

   (c) Are there associated areas treated with conventional herbicide applications or without any vegetation management? If so, describe and give the number of plot replications and the area covered by each.

5. Date and time of observation:

6. Conditions preceding observation (weather, road operational factors, maintenance performed, etc.):

7. Problem(s) intended to be solved by the trial (<u>check all that apply in the space preceding the problem</u>):

__ Drainage-related (__) (__)
__ Visibility for safety (__) (__)
__ Safe vehicle recovery (__) (__)
__ Maintenance worker safety (__) (__)
__ Fire starts (__) (__)
__ Noxious weeds (__) (__)
__ Landscape design (__) (__)
__ Road kills (__) (__)
__ Structural deterioration—
  __ Guard rail posts (__) (__)
  __ Utility boxes (__) (__)
  __ Sign posts (__) (__)
  __ Bridge approaches (__(__)
  __ Light standards (__) (__)

8. Objective(s) of trial (<u>check all that apply in the space preceding the objective</u>):

__ Eliminate vegetation (__) (__)
__ Manage vegetation types (__) (__)
__ Manage vegetation cover (__) (__)
__ Manage vegetation height (__) (__)

Give specific objectives for managing vegetation type(s), cover, and/or height—

9. For each problem intended to be solved by the trial, rate its success in solving the problem at this point in time from 5 (very high) to 1 (very poor). Place the rating in the <u>first parentheses</u> following the problem type in <u>step 6</u> above. Below add any comments that could help in evaluating the trial's success.

10. If there are associated areas treated with conventional herbicide applications or without any vegetation management, rate the success of the strategy in solving the problem at this point in time from 5 (very high) to 1 (very poor). Place the rating in the second parentheses following the problem type in step 6 above. Below add any comments that could help in evaluating the trial's success.

11. For each objective of the trial, rate its success in meeting the objective at this point in time from 5 (very high) to 1 (very poor). Place the rating in the first parentheses following the objective in step 7 above. Below add any comments that could help in evaluating the trial's success.

12. If there are associated areas treated with conventional herbicide applications or without any vegetation management, rate the success of the strategy in meeting the objective at this point in time from 5 (very high) to 1 (very poor). Place the rating in the second parentheses following the problem type in step 7 above. Below add any comments that could help in evaluating the trial's success.

If the problem(s) that are intended to be solved by the trial include drainage, fire starts, wildlife road kills, and/or structural deterioration, fill out the relevant recording sheet(s) attached to Instructions for Observations of Roadside Vegetation in Relation to Road Operation and Maintenance Problems. If there are associated areas treated with conventional herbicide applications or without any vegetation management, make separate observations for the trial and associated areas.