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GUIDELINES MANUAL FOR MINIMIZING WATER QUALITY IMPACTS FROM HIGHWAY MAINTENANCE PRACTICES

Volume IV

March, 1985
Final Report

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16. Abstract

This manual, Volume IV in a four-volume series of reports relating to water quality impacts of highway maintenance practices, provides practical guidance to highway agency maintenance personnel for minimizing impacts to water resources from maintenance practices while keeping highway agency costs at a minimum. The manual identifies those maintenance practices most commonly employed by highway agencies throughout the United States and describes each in terms of its potential for causing adverse impacts to water quality. Available mitigation measures for maintenance practices with the potential to impact water quality are identified, and guidance is given for selecting the most cost-effective practices.

The volumes in this series are:

Volume I - "Highway Maintenance Impacts to Water Quality - Executive Summary" (FHWA/RD-85/057)

Volume II - "Investigations of Impacts of Selected Highway Maintenance Practices on Water Quality" (FHWA/RD-85/058)

Volume III - "A Reference Manual for Assessing Water Quality Impacts from Highway Maintenance Practices" (FHWA/RD-85/059)

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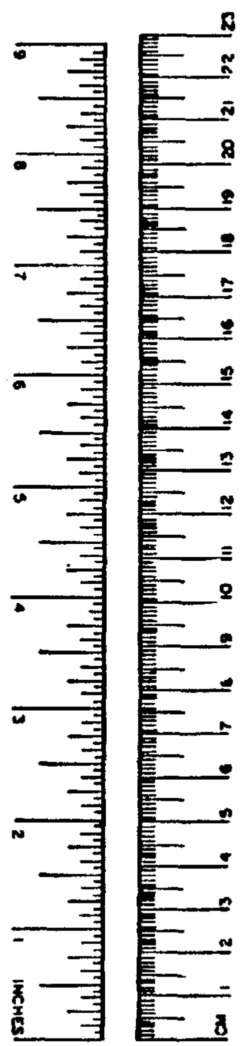
NOTICE

METRIC CONVERSION FACTORS

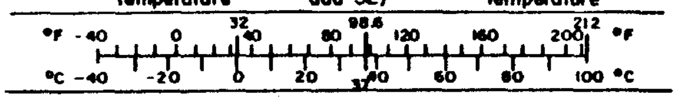
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons(2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temprature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares(10,000m²)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE

This manual is designed to provide practical guidance to minimize impacts to water quality from maintenance practices while minimizing costs. The manual identifies maintenance practices commonly employed throughout the United States. Each is described in terms of its potential for causing adverse impacts to water quality. Available mitigation measures are identified, and guidance is given for evaluating each in terms of cost-effectiveness.

The distinction between maintenance and construction is not always clear-cut. In some agencies, the distinction is based on the nature and extent of the activity; in others, on the amount of money involved. The types of activities considered to be maintenance practices are listed in the next section, based on the conventions of highway agencies contacted during background studies for preparation of this manual.

An attempt has been made to be comprehensive in the identification of maintenance practices, with two deliberate exceptions. Removal of snow and ice by use of deicing chemicals is not covered, nor is emergency response to spills of hazardous materials on highways.

RELATED DOCUMENTS

This manual is part of a four-volume series of reports relating to water quality impacts of highway maintenance practices:

- Volume I: "Highway Maintenance Impacts to Water Quality - Executive Summary" (Report No. FHWA/RD-85/057). This volume provides a concise summary of the major findings and conclusions of this project.

- Volume II: "Investigations of Impacts of Selected Highway Maintenance Practices on Water Quality" (Report No. FHWA/RD-85/058). This report presents the results of a program of field research undertaken to improve the state of knowledge concerning impacts to water quality, resulting from two highway maintenance practices, herbiciding and road surface treatment.

- Volume III: "A Reference Manual for Assessing Water Quality Impacts from Highway Maintenance Practices" (Report No. FHWA/RD-85/059). Volume III provides full descriptions of the potential water quality impacts of maintenance practices presented in this manual. Methods are also detailed for determining whether such impacts are likely to be significant for a specific maintenance project or program.

- Volume IV: "Guidelines Manual for Minimizing Water Quality Impacts from Highway Maintenance Practices" (Report No. FHWA/RD-85/060). This report provides guidance for minimizing water quality impacts for any maintenance activity which may adversely affect water quality.

MAINTENANCE OBJECTIVES AND PRACTICES

The types of activities considered to be maintenance practices (for the purpose of this manual) are listed in Table 1. These have been grouped according to the general purpose they serve, the "maintenance objectives." It is recognized that somewhat different terminology and classification may be applied in different agencies, but each practice is probably readily recognizable and, if not, each is described in this document. More importantly, it classifies the maintenance practices according to their potential impact on water quality according to considerations summarized below.

BASIS FOR IDENTIFICATION OF POTENTIAL IMPACT MAINTENANCE PRACTICES

Several information sources were utilized in identifying maintenance practices which might impact water quality. Information contained in the open literature concerning highway maintenance practices and related water quality impacts was obtained through computerized and manual bibliographic searches. Computer data bases searched included:

- TRIS (Transportation Research Information Services)
- NTIS (National Technical Information Service)
- COMPENDEX (Engineering Index, Inc.)
- ENVIROLINE (Environment Information Center)
- SWRA (Water Resources Scientific Information Center)

Information compiled from the computerized literature searches was supplemented by manual searches. Articles pertaining to standard highway maintenance practices,

Table 1. Highway maintenance objectives and practices.

Maintenance objective	Maintenance practice
Rideability Maintenance	• Pothole patching • Surface repairs • Full depth repairs • Filling and sealing joints and cracks • Surface treatments • Pavement jacking • Planing pavements (bituminous and concrete) • Blading unpaved surfaces
Roadside Maintenance	• Blading and restoring unpaved berms and/or shoulders • Repairing curbs, gutters, and paved ditches • Repairing slopes, slips, and slides • Controlling and disposing of roadside litter
Vegetation Maintenance	• Mowing • Chemical vegetation control • Planting or care of shrubs, plants and trees • Seeding, sodding, and fertilizing
Drainage Maintenance	• Cleaning and reshaping ditches • Cleaning channels • Cleaning drainage structures • Repairing drainage structures
Structural Maintenance	• Bridge surface cleaning • Bridge painting • Bridge deck repair • Bridge joint repair • Substructure repair • Superstructure repair
Safety Maintenance	• Cleaning pavement • Guardrail repair • Snow plowing • Application of abrasives • Crash attenuator repair • Snow fence installation and removal • Highway lighting
Comfort Area Maintenance	• Care of rest areas
Sign Maintenance	• Flat sheet, side-mounted, and overhead sign repair and replacement
Traffic Control Device Maintenance	• Pavement marking
Equipment Maintenance	• Washing and cleaning equipment
Storage and Handling Materials	• Bulk storage of nonfuel materials • Bulk storage of motor fuels • Disposal of used lubricating oils

innovative maintenance practices, water quality impacts, and mitigative measures were reviewed and cataloged according to maintenance objective.

Researchers actively involved in studies involving highway maintenance practices and their potential water quality impacts were contacted to determine the status of their current research and the availability of any unpublished reports or data. A number of county engineers and experts in State highway agencies across the country were also interviewed for their insights into assessing water quality impacts related to highway maintenance practices. The States contacted were chosen on the basis of geography, topography, climate, and whether there was apparently any ongoing research involving highway maintenance practices. Additionally, specifications and guidance documents concerning the performance of various maintenance practices were obtained to determine any environmentally significant regional differences in the manner in which a specific maintenance practice was carried out. States and counties interviewed include:

- Ohio Department of Transportation
  - Lake County, Ohio
  - Washington County, Ohio
  - Wyandot County, Ohio
- Florida Department of Transportation
- Missouri Highway and Transportation Department
- Texas Department of Highways and Public Transportation
- California Department of Transportation

Two factors were taken into account in evaluating the potential impact on water quality resulting from a specific maintenance practice. The first consideration was the proximity of a given type of activity to a body of water, ditch, or drainage channel. Normally, a maintenance practice taking place in the immediate vicinity of a body of water is more likely to have an impact on water quality than one taking place some distance away. By their nature, some practices are more likely to take place in or near water or drainage devices than others. The second factor was the nature of the materials and methods used in performing that practice. The criteria listed below were used in evaluating each maintenance practice for water quality impact potential. The more these criteria apply to a given practice, or the greater extent to which a criterion describes the maintenance practice, the more likely the practice is to have an adverse impact on water quality. A maintenance practice is more likely to have an impact if it involves:

- Exposing or moving soil or sediments, including activities that result in accidental or incidental removal of vegetative cover.
- The use or disposal of toxic chemicals or materials with toxic components, especially if such components are leachable.
- The use or disposal of materials containing plant nutrients.
- The use or disposal of decomposable organic materials.
- The use or disposal of materials that could change the turbidity, pH, or suspended or dissolved solids content of the receiving body of water.

Based on the above criteria and the potential for water involvement, maintenance practices were classified as either: having a probable impact, having a possible impact, or having no probable impact on water quality. The basis for these criteria, in terms of potential adverse water quality impacts, is briefly described below.

Any maintenance practice which involves exposing or moving soils or sediments is likely to increase erosion from the disturbed area. Increased erosion leads to an increase in the sediment load to a stream. Sediment is, by volume, the greatest single pollutant of surface waters in the United States (Stewart et al., 1975) and is an important cause of adverse water quality effects. Most sediment comes from cultivated croplands and construction sites, but highway maintenance activities can be locally important sources. Increased sediment loads can be harmful to the aquatic environment in several ways: (1) increased siltation may smother bottom-dwelling organisms or sufficiently alter the habitat so as to affect fish and shellfish feeding and reproduction; (2) sediment abrasion can damage fish gills and injure other forms of aquatic life upon which fish depend for food; (3) increased sediment loads may increase turbidity sufficiently to depress photosynthesis by aquatic plants; (4) suspended sediments provide a surface for the growth of microbes; and (5) increased sediment loads may increase the absorption of nutrients and toxic chemicals (Swerdon and Kountz, 1973). In many situations, sediments destroy the attractive appearance of waters and diminish their recreational value.

Practices involving the use or disposal of toxic chemicals or materials pose acute and chronic toxicity threats to fish and other aquatic life in the receiving water body. Toxic effects to organisms at any level of the aquatic food chain can have deleterious effects on the entire system. Toxic chemicals can also pose a threat to human health through contamination of drinking water supplies and food fish and shellfish. Both surface and groundwaters used for drinking can be affected.

Maintenance practices involving the use or disposal of plant nutrient-containing materials (phosphate, nitrate, ammonium salts, etc.) may accelerate a natural process called eutrophication, or nutrient enrichment, of the receiving water bodies. The effects of accelerated eutrophication are almost always undesirable and include an over-production of aquatic plant life in general, a shift of the dominant algal species from green to blue-green species (the latter tend to be slimy, malodorous, and toxic), and a reduction in dissolved oxygen levels which may lead to a shift to less desirable fish populations or, in severe cases, fishkills (Farnworth et al., 1979).

Maintenance practices involving the disposal of decomposable organic matter may alter the oxygen balance of the receiving waters. Oxygen consumed by decomposition of the organic matter may lead to a shift in fish populations, release of nutrients and toxics bound to the sediments, and an increase in the toxicity of some pollutants to fish (Welch, 1980). Additionally, nutrients generated from the decomposition of the organic matter may contribute to the eutrophication process. Wet material such as grass clippings or sewage is of much greater concern than woody trash because of its much more rapid rate of decomposition.

Maintenance practices which involve the use or disposal of materials which could alter the pH, turbidity, or suspended or dissolved solids content of a receiving water body may have varied impacts. Alterations in turbidity and solids content would have impacts similar to those from increased sediment loading. An alteration in pH may increase the toxicity of some chemicals and increase the desorption of materials adsorbed to the sediments (Welch, 1980). The resulting resolubilization of metals, other toxic materials, and nutrients may have negative impacts on the aquatic environment in terms of increased toxicity and eutrophication (Farnworth et al., 1979).

The results of the evaluation of specific maintenance practices on the basis of their potential for causing water quality impacts are presented later in this manual.

EVALUATION OF MITIGATION MEASURES

It does little good to point out which maintenance practices are likely to adversely affect water quality unless some realistic suggestions can be made as to how to avoid or reduce such impacts. Highway maintenance activities are essential to ensure the safety of highway users and protect the public investment in highways. Any suggestions as to how to avoid or reduce water quality impacts will have little effect on highway agency practices unless they pass the test of practicality. That is, the mitigation measures must work, but not impose unacceptable costs on the agency or costs that are out of line with the benefits to be realized. In other words, mitigation measures must be cost-effective.

In the following discussion, the term mitigation measure refers to two different approaches to minimizing or preventing water quality impacts: an alternative maintenance practice (AMP); or an "add-on" procedure to an existing maintenance practice to reduce its potential for producing impacts which, taking the two together, is called a modified existing maintenance practice (MEMP).

In evaluating the cost-effectiveness of mitigation measures, three general factors were considered:

1. Effectiveness in Meeting the Maintenance Objective - an AMP or MEMP must accomplish the desired maintenance objective or not unduly interfere with achieving the objective.

2. Effectiveness in Protecting Water Quality - the mitigation measure must prevent or reduce the water quality impacts potentially produced by the maintenance practice in question.

3. Cost Differentials - the ideal mitigation measure would be less costly than the maintenance practice that it modifies or replaces, or at least no more costly. This may sometimes be the case, particularly if the mitigation measure is an AMP. More realistically, most mitigation will involve some extra cost. Whether a highway agency adopts a particular mitigation measure depends, in part, on how much more costly it makes accomplishment of the maintenance objective. Other important considerations are time and available manpower.

Effectiveness in Meeting the Maintenance Objective

For many objectives this manual lists more than one practice by which the objective can be accomplished. In such cases, no "best" practice is identified. The existing practices are presumed to be not only effective, but also cost-effective when water quality protection is not a consideration. It is recognized a practice may be cost-effective for one agency but not for another for reasons of equipment availability, local labor costs, and a variety of climatic, geologic, and other site factors. Therefore, when an AMP is available which may have less impact on water quality than the existing practice, it still may not be practical.

The manual also describes available "add-on" mitigation procedures for many maintenance practices. These activities can be done in conjunction with an existing maintenance practice for no other reason than to minimize or prevent a water quality impact. In every case, these add-on procedures are in use by at least some highway agencies and are presumed not to interfere with accomplishment of the maintenance objective, although they typically increase costs.

Effectiveness in Protecting Water Quality

An extensive effort was made during the preparation of this manual to evaluate the effectiveness of available mitigation measures in minimizing or preventing water quality impacts. This included, as noted previously, an intensive search of the scientific literature, interviews with State and local highway agency experts, and contact with numerous researchers nationwide. In spite of this effort, little conclusive or scientifically verified information concerning the effectiveness of mitigation measures in use was found.

Due to the lack of extensive scientific data on the effectiveness of mitigation measures, a common sense approach was used in conjunction with what information there is to evaluate the probable effectiveness of mitigation. In so doing, mitigation measures may be placed in four categories which, generally speaking, are related to their probable effectiveness. In decreasing order of effectiveness these are:

- Avoidance - use of alternative maintenance practices that avoid the impact altogether. For example, the use of a herbicide immediately adjacent to a water course, with potentially adverse effects on fish or other aquatic life, can be avoided by mowing in such locations.

- Substitution - use of a less harmful material in place of a substance that may produce serious impacts to water quality. For example, a less toxic herbicide could be used in the situation described above. The substitution may not completely eliminate the adverse water quality effect (toxicity), so it cannot be considered as effective as avoidance. Also, the substitution may not be as effective in meeting the maintenance objective as the original herbicide, that is, it may not control the target vegetation as well, and it may be more expensive to use.

- Control - use of measures to prevent the polluting material generated by a maintenance practice from actually entering a receiving water. In the case of herbicides, this could include the use of a "sticking agent" (surfactant) to ensure that the herbicide firmly adheres to the vegetation to which it is applied, or the use of an "anti-drift agent" to prevent droplets of spray drifting to nontarget areas. Another example is the use of various erosion control measures to prevent sedimentation of receiving waters and, perhaps, to prevent the introduction of other pollutants that may be carried by sediments.

- Removal - use of measures to remove maintenance-generated pollutants once they are in the receiving water or drainageways leading to them. An example is the use of retention ponds or catch basins to trap sediments. Available information suggests that such devices are of limited value, for they retain mainly the larger sediment particles; finer particles are not efficiently captured by such structures and most of the other pollutants are either carried by fine particles in suspension or are in solution. Another limiting factor is that to the extent pollutants are trapped by such devices, they remain available for resuspension by the next flush of stormwater. A more effective, although not very practical method, is the use of silt fences to trap sediments.

Evaluating Cost Differentials

Most highway agencies keep records for annual costs of various maintenance practices. However, in order to compare the cost of an existing maintenance practice with an AMP or MEMP it is necessary to develop costs per some common unit of work. The following section describes how unit costs were developed for this manual. The unit costs presented are suggestive of what actual costs may be for a particular highway agency. The costs presented are based on records for maintenance practices currently in use at a number of agencies and do not reflect certain additional costs that an agency might incur in adopting a new mitigation measure (including AMP). Such additional costs include the cost of:

- New or additional equipment (which should be amortized over the expected useful lifetime of the equipment), unless existing equipment is to be replaced in any case.
- Additional manpower, if any.
- Retraining current personnel, if necessary.
- New or substitute material.

In general, the AMP or MEMP mitigation measures described in this manual can be used by most highway agencies (or their contractors) with existing equipment and personnel, so, with the possible exception of materials costs, the additional cost factors listed above generally do not need to be considered. However, an agency that is interested in more precise cost estimates than those presented in this manual can use the method presented here and data from its own cost records to generate its own unit cost estimates.

Development of Cost Information

Unit cost figures were derived from cost figures obtained during interviews with State highway maintenance agencies from those States listed earlier. Cost figures are presented in terms of a basic work unit for each type of maintenance practice, and generally a range of costs is shown because no single cost figure is representative.

The weighted average approach (relative value of an item in a statistical compilation) was used to show unit cost ranges for several practices. The following example illustrates this approach. If Company A builds 100 units at a total cost of $1,000 or $10 per unit and Company B, in response to a smaller order, builds 10 identical units but at a total cost of $210 or $21 per unit, the weighted average is $1,210 divided by 110 units or $11 per unit. A simple arithmetical average would be $10 plus $21 divided by 2, or $15.50 per unit.

Extrapolation was used to estimate those values of a magnitude or a function which lie beyond the range of known or determined values. For the most part, it was used to establish cost of mitigation measures, since most mitigation measures have a direct parallel in some other maintenance practice.

In some cases, unit cost ranges are from within a single State, although the majority were compiled from two or more States. A single figure indicates that it was the only one available and therefore may not be a typical cost figure nationally. Most of the figures used were taken from cost records compiled in the latter half of calendar year 1981 and early 1982. Further, the costs are direct costs only, and, as such, do not include labor's fringe benefits, administrative overhead, prorata costs, etc.

Need for Mitigation

Before considering which of the available mitigation measures may be the most cost effective, a determination should be made as to whether any mitigation at all may be needed. Unnecessary mitigation, by definition, cannot be cost-effective. Maintenance practices are categorized in this manual as Type I - Probable Impact, Type II - Possible Impact, and Type III - No Probable Impact. As a rule, the method for evaluating cost-effectiveness would be applied only to Type I practices. A water quality impact from Type II would be highly unusual, and virtually impossible from Type III. Even with Type I practices, the probability of a water quality impact depends on situation-specific factors, and among the most important of these factors is whether the maintenance activity occurs close enough to a receiving water body or a drainage device that a water impact is a realistic outcome.

Research has indicated that grassy vegetation is a very effective filter for trapping sediments and other pollutants in highway stormwater runoff surface flow, so the distance of surface flow over grassy areas should be considered. According to Wang et al. (1982), 197 ft (60 m) of surface flow through grassy vegetation is sufficient to remove pollutants from runoff water, so any maintenance work separated from the nearest drainage device or receiving water by at least 197 ft (60 m) of turf can be presumed not to need any additional mitigation.

For Type I maintenance practices taking place close to the water or a drainage device or separated from such by less than 197 feet (60 m) of turf, professional judgement should be used to determine whether mitigation is appropriate. Detailed methods for evaluating the environmental impacts of maintenance practices are presented in

Volume III of this report series, but these methods are fairly elaborate and are not intended for routine use by the maintenance engineer.

The following list describes high-, medium-, and low-priority waters for protection from maintenance-induced impacts by some form of mitigation. The engineer can readily determine which waters in his geographical area of responsibility fall into which group, based on his knowledge of the area, observation of human activities or uses of the waters, and by calling the local district office of the State natural resources agency.

<u>High Priority</u>

- Waters having high resource values sensitive to pollution (fishing, swimming, drinking water supply, and stock watering).
- Wetlands providing excellent habitat for waterfowl and other wildlife.
- Waters or wetlands providing habitat for endangered species.

<u>Low Priority</u>

- Waters or wetlands which are highly polluted by continuing sources and which have no particular resource values sensitive to water quality.
- Small wetlands located entirely on the right-of-way and resulting from drainage patterns created by the highway.

<u>Medium Priority</u>

- All other waters or wetlands.

Every effort should be made to protect high-priority waters or wetlands from Type I maintenance practices when such activities are not buffered by at least 197 ft (60 m) of grassy surface drainage. Obviously, the closer the activity is to the water or drainage way leading to it, the more urgent the need for a mitigation measure. Medium-priority waters should be protected by mitigation at least whenever the maintenance activity will be directly over or in the water or drainage way, and preferably whenever the activity is separated from the water course by less than 33 ft (10 m) of turf.

Overall Cost-Effectiveness Evaluation

This section presents a method that a maintenance engineer can use to select the more cost-effective mitigation measure, relative to each other and to the existing practice. The method is designed to allow local cost data and other considerations to be factored into determining Relative Cost-Effectiveness (RCE).

The method involves solving an equation with three terms. The terms are relative factor values which are to be determined as described later in this section. The equation is:

$$RCE = A \times B \times C \qquad (1)$$

Factor A - Maintenance Objective Effectiveness - This factor permits consideration of how effective an AMP or MEMP is, relative to the existing practice, in meeting the maintenance objective. The factor values for "A" are:

- 1, if the mitigation measure (AMP or MEMP) is better than the existing practice in meeting the maintenance objective.
- 2, if the mitigation measure is just as good as the existing practice.
- 3, if the mitigation measure is slightly less effectve than the existing practice.
- 4, if the mitigation measure is much less effective than the existing practice.

Factor B - Water Quality Protection Effectiveness - The approach taken to evaluate the effectiveness of mitigation measures in minimizing or preventing potential water quality impacts was discussed earlier in this document. With reference to the factors noted earlier, and in lieu of better data, mitigation measures can be rated on whether they involve "avoidance, substitution, control, or removal." The factor values for "B" are:

- 1, if the mitigation measure is most effective (i.e., avoidance).
- 2, if the mitigation measure provides less effective, but still good protection (i.e., substitution).

- 3, if the mitigation measure is even less effective (i.e., control).
- 4, if the mitigation measure is least effective (i.e., removal).

Factor C - Unit Cost Ratio - The factor value for "C," the unit cost ratio is calculated:

$$\text{Unit Cost Ratio} = \text{Unit Cost for AMP or MEMP} \div \text{Unit Cost for Existing Maintenance Practice} \qquad (2)$$

Unit costs may be taken from the values reported later in this manual or may be developed from agency records when appropriate. Many of the unit costs presented here are given as ranges. Use of the median value from the range is advisable unless the engineer making the evaluation has reason to believe a higher or lower value is more accurate in the case of his agency.

Sample Calculation

Below is a sample calculation for determining the Relative Cost-Effectiveness of using sod or jute matting to mitigate water quality impacts following the cleaning of a drainage channel.

Mitigating measure = Sodding

Factor A = 2

Factor B = 3

Factor C = $3.99/lin ft ÷ $2.74/lin ft = 1.46

RCE = 2 x 3 x 12.46 = 8.76

Mitigating measure = Jute Matting

Factor A = 2

Factor B = 3

Factor C = 3.37/lin ft ÷ $2.74/lin ft = 1.23

RCE = 2 x 3 x 1.23 = 7.38

Calculation Worksheet

Below is a calculation worksheet to assist the highway maintenance engineer in determining the relative cost-effectiveness of mitigating measures, using the method described above.

Mitigating measure = ________________________

Factor A = ___

Factor B = ___

Factor C = ______________ ÷ ____________ = ___________

RCE = ___________ x ___________ x ____________ = ____________

Summary of Cost-Effectiveness Evaluation Method

The method presented above for evaluating and selecting the most cost effective mitigation measure to prevent or minimize water quality impacts is summarized in Table 2. In this method, the lower the Relative Cost-Effectiveness value for a particular mitigation measure, the more it is cost-effective.

SUMMARY OF OVERALL PROCESS

The overall decision process described previously for determining the need for mitigation to minimize water quality impacts from a specific maintenance activity or program and for evaluating the availability of cost-effective mitigation measures is summarized in Figure 1.

Table 2. Summary of method for evaluating the relative cost-effectiveness of mitigation measures.

For a given mitigation measure, the Relative Cost-Effectiveness is given by:

$$RCE = A \times B \times C$$

where the factor values for each term are:

A	B	C
Maintenance objective effectiveness Re: Existing practice	Water quality protection effectiveness	Unit cost ratio
1. Better than	1. Most (= Avoidance)	
2. Just as good as	2. Good (= Substitution)	Unit Cost Ratio =
3. Slightly less than	3. Less (= Control)	$\frac{\text{Unit Cost for AMP or MEMP}}{\text{Unit Cost for Existing M.P.}}$
4. Much less than	4. Least (= Removal)	

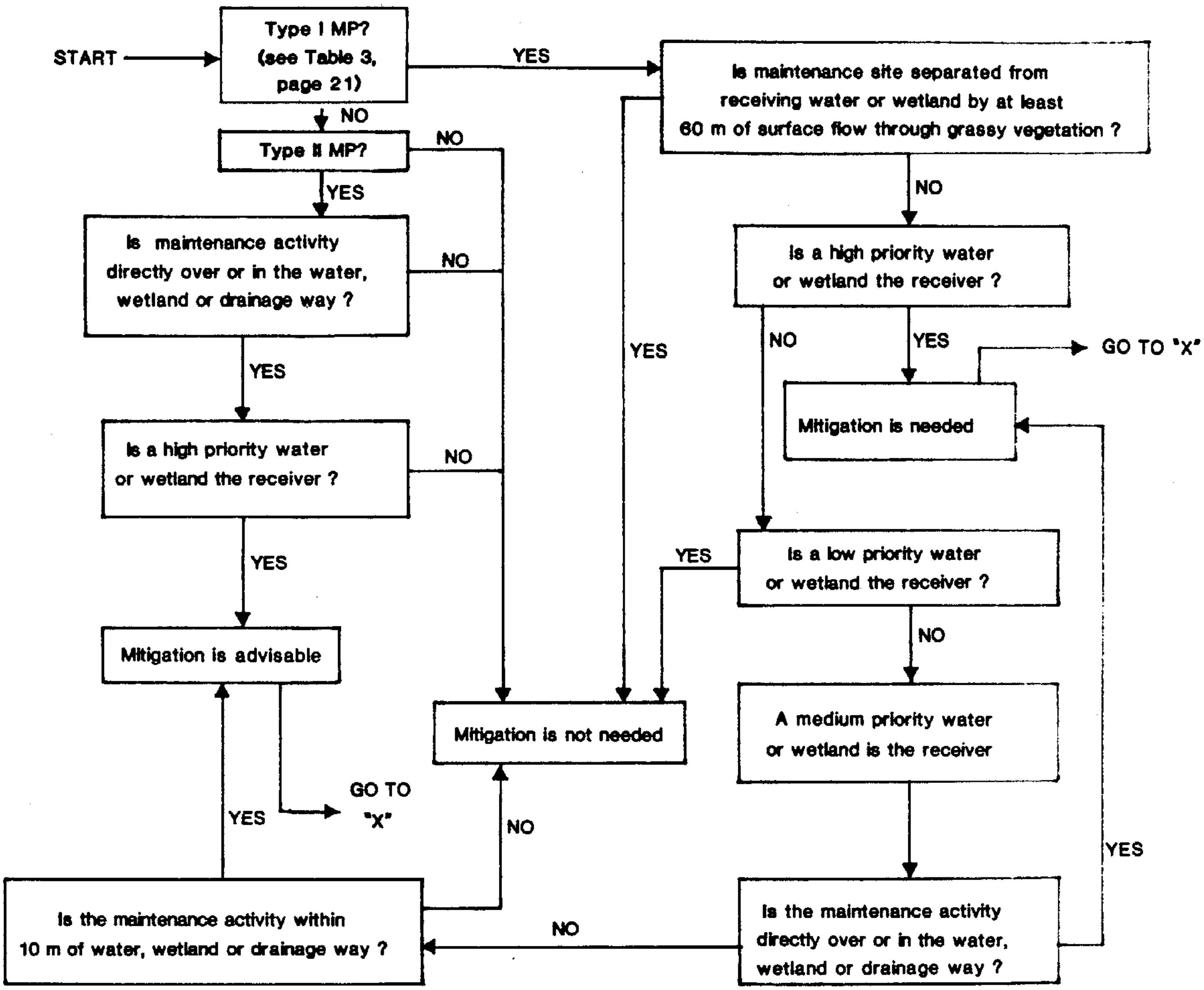

Figure 1. Summary of decision process to determine need for and availability of cost-effective measures to minimize water quality impacts from maintenance practices.

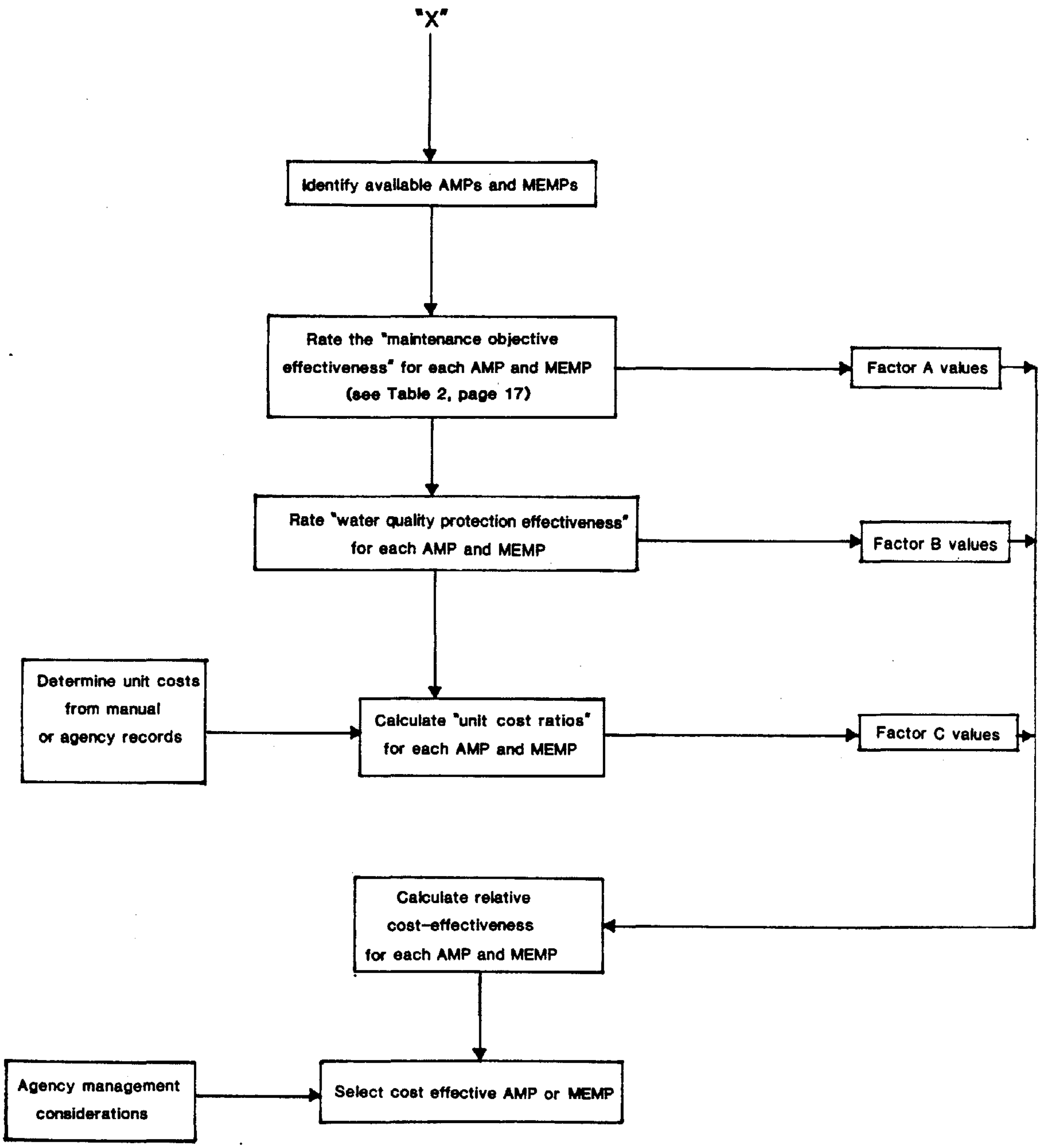

Figure 1. Summary of decision process to determine need for and availability of cost-effective measures to minimize water quality impacts from maintenance practices. (continued)

MAINTENANCE PRACTICES

ORGANIZATION

This section presents information on maintenance practices in three major categories:

- Maintenance Practices Which Can Have a Probable Impact (Type I)
- Maintenance Practices Which Can Have a Possible Impact (Type II)
- Maintenance Practices Which Have No Probable Impact (Type III)

Table 3 indicates to which of the above classes each of the maintenance practices belongs, based on the findings of the research process previously described and field studies conducted as part of this project.

Within each category of this section, each maintenance practice is named and under each practice the following information is provided, as appropriate:

- Description - Procedures used in the stated maintenance practice.
- Materials Used - Types of materials employed in each practice.
- Equipment Needed.
- Estimated Cost Per Work Unit - Includes a definition of the work unit; costs based on late 1981 and early 1982 estimates.
- Potential Water Quality Impact - General rationale for considering the activity to potentially impact water quality.
- Possible Mitigation Measures - Only MEMPs are described; AMPs are maintenance practices in their own right and are described as such.
- Esimated Costs of Mitigation Per Work Unit.

For the Type III maintenance practices, the last four items are generally omitted because of lack of applicability.

Table 3. Maintenance practices organized according to water quality impact types.

Maintenance practices which can have a probable impact (Type I)

- Repairing slopes, slips, and slides
- Cleaning ditches, channels, and drainage structures
- Repairing drainage structures
- Bridge painting
- Substructure repair
- Chemical vegetation control

Maintenance practices which can have a possible impact (Type II)

- Full depth repairs
- Surface treatments
- Blading and restoring unpaved berms and/or shoulders
- Repairing curbs, gutters and paved ditches
- Bridge surface cleaning
- Bridge deck repairs
- Mowing
- Planting or care of shrubs, plants, and trees
- Seeding, sodding and fertilizing
- Application of abrasives
- Care of rest areas
- Washing and cleaning maintenance equipment
- Bulk storage of motor fuels
- Disposal of used lubricating oils

Maintenance practices which have no probable impact (Type III)

- Blading unpaved surfaces
- Pothole patching
- Surface repairs
- Filling and sealing joints and cracks
- Pavement jacking
- Planing pavements - bituminous and concrete
- Bridge joint repair
- Superstructure repair
- Cleaning pavement
- Guardrail repair
- Snow plowing
- Crash attenuator repair
- Snow fence installation and removal
- Highway lighting
- Flat sheet, side-mounted, and overhead sign maintenance
- Pavement marking
- Bulk storage of non-fuel materials
- Controlling and disposal of roadside litter

MAINTENANCE PRACTICES WHICH CAN HAVE A PROBABLE IMPACT (TYPE I)

Repairing Slopes, Slips, and Slides- Type I

Description - Slope repair is often necessary along the sides of the highway because of erosion (formation of gullies) and minor slipping and sliding (often called sloughing). The basic approaches used are to fill the eroded areas with earth or, where this is unlikely to last, with rock or paving material. Often, an interceptor or diversion ditch is used on cut slopes to eliminate further erosion of gullies, and the newly formed ditches are then sod-lined or riprapped. The newly repaired slope is seeded and mulched. In more extensive repairs, planting of shrubs and small trees is desirable and often necessary.

To properly repair a slip or slide requires extra-ordinary measures, skill, time, and money. The accepted highway terminology for a slide is the movement of an earth mass on the upper side of the road so as to seriously disturb the structural integrity of the facility. A slip is defined in the same manner, except it is located on the lower side of the road. The underlying cause of most slips and slides is water. The driving of piling, placing cellular retaining walls, and making rock fills is the "symptomatic" approach to treating the effect. Finding, intercepting, and disposing of the offending water is treating the cause and is both the correct and more permanent repair.

Materials Used - Earth, rock, grass seed, fertilizer, mulch, wire stakes, emulsions, shrubs, seedling trees for repairing slopes; steel, concrete, drain pipe, aggregate and quarried rock for repairing slips and slides.

Equipment Needed - Trucks, bulldozers, motor graders, compactors, piling drivers, cranes, power shovels, hauling scrapers, tamping rollers, welders, hand tools.

Estimated Cost Per Work Unit -
Earth fill - \$1.75 to \$2.35/yd^3 (\$2.28 to \$3.06/m^3).
Rock fill - \$70 to \$80/yd^3 (\$91 to \$104/m^3).
Interceptor ditch (riprap) - \$30 to \$40/yd^2 (\$36 to \$48/m^2).
Interceptor ditch (sodded) - \$3 to \$5/yd^2 (\$3.60 to \$6.00/m^2).
Pile driving - \$56 to \$92/lin ft (\$184 to \$302).
Cellular retaining walls - \$234 to \$360/yd^2 (\$195.65 to \$301.00/m^2).

Potential Water Quality Impact - The potential impact associated with repairing slopes, slips, and slides is soil erosion and the increased resultant sediment and nutrient load to receiving waters. Of course, the condition being corrected has the same sort of impact potential and would probably be worse than the effect of the maintenance activity if allowed to continue. The various maintenance measures that can be used differ in their potential for water quality impacts, and the engineering analysis of the geologic and earth conditions will govern the formulation of corrective action.

Of the various maintenance measures used, pile driving probably causes the least disturbance of soil and has little or no potential for affecting water quality. Building some type of retaining wall or rock fill requires excavation and exposing soils for some time period, with potential for soil erosion. Constructing walls and rock fills might cause a short-term impact on water quality, due to erosion. Unfortunately, the most effective and permanent maintenance approach, i.e., finding, intercepting, and disposing of the offending water, generally involves more disturbance of soils and the greater risk of water quality impacts. However, because of the nature of this type of repair, the proper corrective measure is more important than selecting a lesser impact measure.

Possible Mitigation Measures - For major repairs involving extensive excavation, an erosion and sediment control plan should be developed, particularly if repairs are in the vicinity of major water bodies. As a standard practice, seeding and mulching is the most practical mitigation approach if it involves filling with earth. Sodding would be another, more expensive alternative. The use of straw bales and silt fences are also effective control measures, the latter being more effective although also more costly. If the eroded slope is repaired by filling with rock or some paving mix, seeding would be inappropriate. Plantings might be used in some instances to achieve stabilization. Generally, careful erosion and sediment control practices should be employed during repair operations involving earthwork.

Estimated Cost of Mitigation Per Work Unit -
Seeding and mulching (includes lime and fertilizer) - \$0.35 to \$0.40/yd^2 (\$0.42 to \$0.48/m^2).
Plantings - \$1.00/yd^2 (\$1.2/m^2).
Sodding - \$2 to \$3/yd^2 (\$2.40 to \$3.60/m^2).
Straw bales - \$2.25 to \$2.75/bale, including installation
Silt fences - \$2.90 to \$4.00/ft (\$9.53 to \$13.14/m)

Cleaning Ditches, Channels, and Drainage Structures - Type I

Description - To clean and reshape ditches, excess material must be removed and the ditch restored to its original cross section, in both line and grade, to allow for normal functioning and design capacity. Depending on the scope of the deficiency, it can be accomplished by hand methods, tractor backhoe, motor grader, or truck-mounted excavator. In most cases, the excavated material is loaded on trucks and hauled to a disposal site located in or out of the highway right-of-way.

The removal of vegetative growth and sedimentary deposits to restore the channel to its proper cross section and correct grade are the primary goals in a channel-cleaning operation. Returning a blocked channel to its proper section, line, and grade involves the use of sizeable earth-moving equipment. The removed earth is generally used as fill material nearby rather than being hauled away. Chemical sprays or herbicides are sometimes used to delay or stop vegetative growth.

Cleaning of drainage structures can vary from simple removal of a few shovelfuls at the outlet end to the complete digging-out and hauling away of many yd^3 (m^3) from a completely or nearly closed structure. Smaller drainage structures, except for deposits and trash resulting from cloudbursts and flashfloods, require only minor cleaning each year. Most culverts require only the removal of minor amounts of sedimentary deposits at the outlet end or some rearrangement of the earth or sod at the inlet end to allow for the correct entrance of the running water. Catch basins differ. The deposited solids are seldom flushed away, but are removed with shovel or other suitable tool and hauled away. Maintenance crews often use a vactor jet which adds pressurized water to liquify the deposits and then sucks it up into a disposal compartment on the same truck unit.

Materials Used - Chemical brush killers, woody plant herbicides, and nonselective herbicides. Water for flushing drainage structures.

Equipment Needed - Hand shovels, power graders, tractor backhoes, truck-mounted excavators belt loaders, drag lines, bulldozers, sewer rodders, hand augers, water tanks, vactor jets, dump trucks.

Estimated Cost Per Work Unit -
$0.35 to $0.80/lin ft ($1.15 to $2.62/lin m) of ditch.
$2.01 to $3.46/lin ft ($6.59 to $11.35/lin m) of channel.
$50 to $61/drainage structure.

Potential Water Quality Impact - Ditch cleaning may increase stream siltation and turbidity. Expected impacts in receiving streams would include degradation of benthic habitat, modification of aquatic life habitat, changes in water chemistry, and resuspension of nutrients and toxic pollutants. The severity of these impacts, however, would depend on the proximity of the ditch to the receiving stream, the size of the ditch, the area of exposed soil, and the duration and volume of water flowing through the ditch.

With channel cleaning, some downstream turbidity and siltation is bound to occur with the use of earth-moving equipment, but it should be of short duration. Toxicity to aquatic life from the use of chemical brush killers, woody plant herbicides, or nonselective herbicides is a probable impact.

Drainage structure cleaning may impact water quality through possible resuspension in runoff of toxic pollutants (e.g., lead, copper, zinc) originating from highway operations. Such potential impacts are probably minor except when a large, badly clogged structure is being cleaned.

Possible Mitigation Measures - For ditches, a number of mitigating measures might be tried, but the results are always in doubt. Sodding or seeding and mulching the exposed areas are possible. The use of jute matting may also reduce potential erosion. Due to seasonal limitations, the chances of establishing a vegetative cover from seed are particularly poor. Also, potential impacts may be reduced by cleaning and reshaping only small portions of ditches, followed by intensive revegetation efforts. This allows undisturbed areas of the ditch to trap sediment. Moreover, careful consideration of the basic need for cleaning the ditch should be given, as it may not be necessary if adequate stormwater drainage does not present a hazard to the highway or its users.

For cleaning ditches and channels, chemical vegetation control should be avoided because of the probable toxic effects to aquatic life. If a herbicide or brush control agent must be used, select one which is least likely to have severe toxic effects according to the method in Appendix A. In the more highly erodable soils, side slopes can be protected with sod or riprap or jute matting. One of these mitigating measures should be a must if in the immediate watershed of a surface water supply source. In such cases, chemical vegetation control should be avoided because of possible adverse human health effects. Seeding and mulching is generally not effective.

In the case of drainage structures, management can probably improve on this practice by insisting on improved job practices. Material removed from catch basins should be loaded and hauled to an approved disposal area. Care should be used in unloading vactor jets or dump trucks to insure that materials are not carried back into a water course.

Estimated Cost of Mitigation Per Work Unit -

Sodding - $1.00 to $1.50/lin ft ($3.28 to $4.92/lin m) of ditch.

Jute matting - $0.50 to $0.75/lin ft ($1.64 to $2.46/lin m) of ditch.

Seeding and mulching - $0.20 to $0.30/lin ft ($0.66 to $0.98/lin m) of ditch.

Riprap - $5 to $10/lin ft ($16.40 to 32.80/lin m) of ditch.

Alternative herbicides - compare costs per acre to be treated, considering application rates and any differences in machinery and labor required. (Savings may be realized if ditches or channels do not need cleaning.)

Drainage structures - $12.50 to $18.25/each structure (i.e., increased costs of 25 to 30 percent).

Repairing Drainage Structures - Type I

Description - The concern with repairing or replacing culverts, storm sewers, catch basins, drop inlets, manholes, subbase drains, etc., is that this type of maintenance is generally corrective as opposed to preventative. In the case of culverts, pavement must be cut and removed, generally one-half at a time to allow for the passage of traffic. The fill is excavated above the pipe, the old pipe removed, bedding material placed, new culvert placed to proper line and grade, backfill placed in layers and pavement placed as per "Full Depth Repairs." Finally, the slopes and ditch are shaped and seeded. Some of the same steps would apply to storm sewers and subbase drains. The repair or rebuilding of a catch basin, drop inlet, or manhole involves the use of concrete block, bricks, mortar, or even portland cement concrete (PCC).

Materials Used - Culvert pipe, tile, concrete block, mortar, aggregate, liquid asphalt, asphaltic concrete, or PCC.

Equipment Needed - Air compressor, backhoe or truck-mounted excavator, dump trucks, roller, water pump, etc..

Estimated Cost Per Work Unit - Cost can vary greatly depending on size of structure and magnitude of repair.

Potential Water Quality Impact - Repairing drainage structures may increase the turbidity and suspended solids of a nearby water body through eroding soils disturbed during repairs.

Possible Mitigation Measures - Proper repair of the disturbed slopes by placing riprap, sod, or seeding and mulching is essential to reduce potential water quality impacts. Generally, careful erosion and sediment control practices should be used to reduce potential impacts.

Estimated Cost of Mitigation Per Work Unit - Seeding and mulching will add 8 to 10 percent. Riprap or sodding will add 25 to 35 percent.

Bridge Painting - Type I

Description - Bridge painting is rather basic in that it involves three steps, namely, cleaning and application of primary and finish coatings. Cleaning involves the removal of dirt, rust, loose paint, etc, using scrapers, wire brushes, sandblasting, high pressure water and cleaning agents, compressed air, and various other tools. Prime coating and finish coating simply involves applying paint by use of brush, glove, roller, spray, or a combination of all.

Materials Used - Sand or other suitable abrasive; cleaners; turpentine or mineral spirits thinner; red lead, lead silico-chromate, zinc-rich or red iron-oxide prime paint; aluminum lead silico-chromate, read lead, or chromate oxide finish paint.

Equipment Needed - Hand scrapers, wire brushes, air compressors, spray units, trucks, ropes, scaffolds, brushes, rollers, mitts, chipping hammers.

Estimated Cost Per Work Unit - $100 to $130/gal ($26.42 to $34.34/L) of paint (including labor and equipment).

Potential Water Quality Impact - Bridge painting may impact water quality if it takes place over standing or running water. Possible water-related impacts include increased sediment load from paint chips and blasting abrasives, potential toxicity to aquatic life from direct entry of paint or cleaners into stream. Recent studies indicate that release of metals contained in paint chips probably does not significantly impact water quality or aquatic life (Parks and Winters, 1982). Repainting overpass structures which do not span permanent or intermittent streams is very unlikely to impact water quality.

Possible Mitigation Measures - Shrouding or other collection systems during sandblasting of structures over water is probably desirable and estimated to collect about 50 percent of the paint chips and sand particles. Blasting and cleaning should not be performed on days of high winds, to ensure collection of the spent material. Floating straw or boom-type collectors prevent entry of the paint into the waterway. Airless sprayers (rather than compressed air sprayers) in those cases where spraying is permitted will reduce overspraying. The use of cleaners should be avoided completely if the operation takes place near streams or sewers likely to discharge directly to streams.

Estimated Cost of Mitigation Per Work Unit - Shrouding will add 20 to 30 percent to cost. Floating straw or boom-type collectors will add 10 to 15 percent to cost.

Substructure Repair - Type I

Description - Substructure repair involves repair of abutments, piers, wing walls, and support piling. Although not an integral part of the bridge structure, paved or rip-rapped slopes may be involved. Abutments seem to cause the most trouble. Back walls split off and the entire abutment structure can settle or tend to overturn.

Replacing an abutment, pier, bent, or wing wall is a major operation, causing a major disruption with large quantities of disturbed earth, broken concrete, etc. Quite often it is over or in the near proximity of water.

A broken abutment backwall is one of the most common problems. Here a portion of the pavement must be removed to provide a work area. Then all loose or unsound material must be removed, possibly holes drilled for additional dowel bars, reinforcing steel cleaned and straightened, the area "squared-up," all needed forms built, a high quality concrete placed, well-consolidated, finished, and cured.

Pier repair mostly involves disintegrated concrete so most of the materials and techniques have been described already. Portions of piers and support piling may be under water. Work on underwater portion of piers may require diking or building of cofferdams. Wing walls tend to overturn or split so it may be necessary to replace all or portions of them. Disintegration of the concrete is repaired as previously described.

Materials Used - Aggregate, cement, epoxy, reinforcing steel, structural steel, timber.

Equipment Needed - Air compressor, concrete mixer, dump trucks, water pump, crane/pile driver.

Estimated Cost Per Work Unit - $15.23 to $17.81 per man-hour.

Potential Water Quality Impact - Substructure repair work quite often takes place over or in near proximity of water and thus probably impacts nearby water bodies: bank erosion from the use of heavy equipment, disturbance of stream bed sediments, turbidity from sediment disruption, and the use of materials which may alter water chemistry.

Possible Mitigation Measures - Disposal of debris in a proper manner and the protection of disturbed earth areas are the major practical concerns. The use of sediment traps in the form of straw bales or fabric filter cloth has been used to mitigate potential impacts. In general, an effort should be made to minimize activities involving disturbance of soils near streams, as well as any in-stream work.

Estimated Cost of Mitigation Per Work Unit -
Proper debris disposal - add 6 to 8 percent.
Slope paving, riprap, etc. - add 10 to 12 percent.
Straw bales - $2.25 to $2.75/bale, including installation.
Fabric filter - $2.90 to $4.00/ft ($9.53 to $13.14/m).

Chemical Vegetation Control - Type I

Description - Chemical vegetation control involves the application of herbicides along guardrails and fences, around signposts and slopes and grassy areas. Basically, there are three classes of herbicides in use today by highway agencies: (1) selective, (2) nonselective, and (3) growth retardants.

Selective herbicides are used to control or kill grasses, broadleaf weeds, and other undesirable vegetation without seriously injuring more desirable plants among which they are growing. Herbicides within this class may be further characterized according to whether they (1) act through direct contact with the plant, or (2) are applied to the plant or soil and subsequently move through the plant, via translocation, to destroy the leaf and root systems.

Nonselective herbicides, often referred to as soil sterilants, kill vegetation without regard to species. Such herbicides are generally employed to control or eliminate all vegetation under and in back of guardrails, sign posts, and around bridge abutments.

The third group, growth retardants, limits the growth height of desirable species and reduces or eliminates machine mowing.

Herbicides come in liquid concentrates, wettable powders, or granules. Granules are applied as is by scattering. In the case of concentrates and wettable powders, with the addition of water and sometimes a small percentage of a surfactant, the prepared solution is applied by truck or tractor-mounted pressurized sprayers, portable back-pack or hand-held sprayers, roller or wick devices which physically wipe the herbicide solution directly onto the plant, or sometimes aerially.

Materials Used - Herbicides, surfactants, water.

Equipment Needed - Trucks, tractors, pressure sprayers, and, in some cases, water tanks.

Estimated Cost Per Work Unit - $1.37 to $1.53/gal ($0.36 to $0.40/L) of mix, i.e., after dilution.

Potential Water Quality Impact - Volume II of this report series presents methods and results of field investigations regarding the levels and toxicity of two herbicides, 2,4-D and picloram, found in stormwater runoff before and after typical application within the highway right-of-way. Based on this study, the above, commonly-used herbicides were found to be present several weeks after application, but well below levels toxic to aquatic life. Thus, any impacts concerning the above herbicides are not likely or will be of short duration, depending on the amount of materials used, frequency of application, and receiving stream flow stage.

With respect to herbicides not field tested in the above study, there is a potential for impacts, but probably of short duration. Again, these effects depend on the amount of herbicide used, frequency of application, and stream flow. Other factors which may affect the degree and extent of impacts include the persistence of the herbicide in the environment and its tendency to accumulate (bioconcentrate) in aquatic species.

In addition, certain granular, slow-release formulations of soil sterilants may be washed into receiving waters, thus presenting a direct risk to aquatic life. Moreover, over-application of soil sterilants may remove vegetation to the extent that soils are exposed and therefore subject to erosion, ultimately contributing to stream sedimentation.

Possible Mitigation Measures - Two general methods of mitigation are recommended. First is to ensure that herbicides are applied correctly. The best way to ensure that operating personnel and supervisors know the proper procedures and safety precautions is to have them become certified applicators for right-of-way pest control. Certification is granted by the responsible State agency which also provides short course training in preparation for the certification exam.

The second general method to minimize impacts is to choose a herbicide least likely to produce toxic effects in receiving waters, taking into consideration its toxicity, mobility, and persistence in the environment, and the recommended application rates. This is a major undertaking, best accomplished on a statewide basis in consultation with knowledgeable experts at local departments of agriculture or universities. Some guidance for herbicide selection is provided in Appendix A of this manual.

Proper application includes ensuring that the herbicide comes in contact with only the target vegetation in the right-of-way and then remains there until it loses effectiveness. The use of anti-drift agents when spraying and surfactants with liquid formulations, regardless of method of application, to ensure proper contact and adhesion to the vegetation may be considered mitigation measures; but costs should probably not be assigned to water-quality protection. Drift control is usually to protect sensitive crops in adjacent fields; surfactants increase the effectiveness of the herbicide in controlling the target vegetation. Drift control is also afforded by other proper management practices. Ideal field conditions for herbicide application are still air or with very low wind velocities, and a very low probability of precipitation. The early morning hours and late afternoon-evening hours generally afford the best conditions. Low volatile formulations and minimal sprayer air pressures, consistent with target distances, are also desirable.

Herbicides should not be used to control vegetation in waterways, wetlands, or drainage courses unless specifically licensed for that purpose. Generally, if such vegetation must be controlled, it should be by mechanical means if costs permit.

Estimated Cost of Mitigation Per Work Unit - The cost of certification of operating personnel and supervisors is for the paid time involved in training and taking the examination.

The use of surfactants and drift control agents may add 10 to 20 percent to materials costs, but as noted, this cost should probably not be attributed to water-quality protection. The cost of the use of an alternative herbicide should be compared with that of the herbicide currently used, considering the recommended application rates and any differences in machinery or labor required.

MAINTENANCE PRACTICES WHICH CAN HAVE A POSSIBLE IMPACT (TYPE II)

Full Depth Repairs - Type II

Description - Full depth repair involves removal and replacement of small areas of pavement (concrete and asphaltic) and berm, including removal and replacement of base material using similar or appropriate material to correct severe cracking, upheavals, pothole clusters, frost boils, and base failures. This restores the pavement or berm to its proper level and strength. It includes the installation of pressure-relief joints.

The first step is to mark and lay out, and then remove the damaged area by sawing (if concrete) or deep scoring or cutting (if asphaltic). Next, all loose or unstable materials are broken out and removed, underdrains are installed, base material placed and compacted in lifts not to exceed 6 in (15 cm), light and uniform tack coat is applied to new base and perimeter face, and then bituminous mixture or concrete is placed in excavated area in layers. If portland cement concrete (PCC) is used, a curing compound is applied. Waste materials are loaded and removed.

Materials Used - Bituminous mixture, aggregate, concrete, drain pipe, liquid asphalt.

Equipment Needed - Concrete saw, air compressor, backhoe or truck-mounted excavator, dump trucks, roller, bituminous distributor or asphalt kettle, hand tools.

Estimated Cost Per Work Unit - $44.50 to $78.92/ton ($49.06 to $87.00/kkg) of mix.

Potential Water Quality Impact - This type of repair practice may have an impact on water quality due to the generation of fine particulate material from preparation of the area.

Possible Mitigation Measures - Collection of fine particles and debris by carefully sweeping the affected area will reduce the suspended solids load to receiving waters, thus minimizing possible water quality impacts. The collected material should be disposed of properly to avoid introduction into a water body through erosion.

Estimated Cost of Mitigation Per Work Unit - $1.46 to $1.76/ft^2 ($1.75 to $2.11/m^2) to landfill debris.

Surface Treatments - Type II

Description - A bituminous surface can be preserved by slowing or stopping the intrusion of water and rejuvenating the existing surface to prevent further deterioration. At its best, such surface treatment is a preservative treatment only, and it does not enhance rideability or materially add to structural strength.

What exactly is meant by "surface treatment" varies from State to State and even, among maintenance people, person to person. Basically, a liquid bituminous material is sprayed on the pavement surface and then covered with a thin layer of aggregate, such as sand or small stone chips. The liquid used today is of the asphalt family of bitumens and is usually an emulsion and sometimes a cutback. The liquid fills the small cracks and tiny voids and helps to re-cement the individual aggregate particles of which the pavement is comprised. A portion of the cover aggregate is retained, which gives a smoothing action. The fresh aggregate prevents tracking by passing vehicles during the curing or "setting-up" of the liquid asphalt. The exact techniques employed depend on surface type, surface condition, season, available materials, volume of work, equipment; thus, the descriptive terms fog seal, sand seal, chip seal, etc., are used.

In a fog seal, a very fine mist or fog of liquid asphalt is applied, usually 0.05 to 0.10 gal/yd^2 (0.16 to 0.32 l/m^2) to rejuvenate a dry, weathered surface. The amount of liquid is of so little volume and penetrates so quickly that a sand cover is unnecessary. A sand seal is used on a surface that has wide cracks and deep voids. The liquid is applied in greater volume, 0.10 to 0.18 gal/yd^2 (0.32 to 0.57 l/m^2), and is covered with sand at the rate of 10 to 12 lbs/yd^2 (3.8 to 4.5 kg/m^2). The sand mixes with the liquid that has puddled into the wider cracks and voids, forming a sort of mastic that acts as a filler. Also, individual sand grains are cemented to the surface to produce a nonskid pavement. The chip seal is used on surfaces showing even more distress than the two described above. Such surfaces will be very dry, oxidized, have a scabby appearance and even have ravelled-out areas. So it follows more material must be used: liquid applied at the rate of 0.20 to 0.30 gal/yd^2 (0.64 to 0.96 l/m^2) and stone chips at the rate of 15 to 20 lbs/yd^2 (5.7 to 7.6 kg/m^2). A roller, rubber-tired preferably, serves to imbed the stone chips into the congealing liquid. Rollers on a sand seal are optional, depending on conditions.

Emulsions are generally applied at ambient temperatures unless the season is very late and cold. Cutbacks are applied at elevated temperatures in the 140 to 180 °F (60 to 82 °C) range.

Materials Used - Aggregates (sand, stone chips), liquid asphalts (emulsions, cutbacks).

Equipment Needed - Hand tools, power brooms, bituminous distributors, spreader boxes, rollers, trucks, etc.

Estimated Cost Per Work Unit - $1.36 to $2.75/gal ($0.42 to $0.84/L) of liquid asphalt.

Potential Water Quality Impact - The petroleum distillates in cutbacks could present a potential for toxic effects to aquatic life. Impacts from the use of asphalt emulsions are not likely, as demonstrated by field studies conducted during this project (see Volume II).

Possible Mitigation Measures - Care should be taken when using solvents to avoid accidential spills or improper disposal of unused quantities.

Estimated Cost of Mitigation Per Work Unit - None identified.

Blading and Restoring Unpaved Berms and/or Shoulders - Type II

Description - Unpaved berms require constant maintenance: the frequency depends on pavement width and alignment, traffic volume, and seasonal variations. The berm of an average road, due to traffic and water runoff, loses about 20 percent of its aggregate per year, so in addition to blading, lost aggregate must be replaced. The generally accepted method is blading to restore the proper slope and to reposition, compact, and stabilize displaced granular material. Rolling to aid in restabilizing the berm is also desirable.

Blading is done with power graders, light power-controlled blades on the back of wheeled tractors, and simple drags pulled by trucks or tractors. Blading is generally done twice a year, in the spring and fall, but more often in the event of heavy storms or on roads with poor alignment and a high percentage of truck traffic. Blading of berms not only perpetuates a design structural feature of the road but also is dictated for traffic safety, to fill in the "drop-offs" at pavement edge.

Two passes with a grader or other machine are generally required to properly reshape a berm. The first pass is a heavy cutting one to eliminate high and low spots and is done in a manner that pulls all material towards the pavement. This leaves a slight windrow with some of the loose material on the pavement edge. On the second pass, the blade is angled away from the pavement, which not only cleans the pavement edge but further refines and smooths the shoulder surface. If done in the spring and fall when soil moisture is at or near optimum, creation of dust is not a problem. Water or calcium chloride ($CaCl_2$) may be added, ideally, if necessary to blade in the heat and dryness of summer.

Blading shoulders is a bigger operation involving the entire strip from pavement edge to down slope. This can involve removal and disposal of sod and excess earth.

Materials Used - Aggregate, water or $CaCl_2$ for dry, dusty conditions (generally added only once a year).

Equipment Needed - Power graders, berm maintainers, drags, rotary brooms, water tanks, rollers.

Estimated Cost Per Work Unit - $71.80 to $113.08 per shoulder mile ($44.88 to $70.68/shoulder kilometer).

Potential Water Quality Impact - Blading of unpaved berms is not likely to cause water quality impacts in flat terrain; but in hilly and mountainous terrain some minor temporary sedimentation impact is possible. Blading shoulders involves a greater potential for water-quality impact than does blading berms by virtue of the larger disturbed area.

Possible Mitigation Measures - If blade maintenance is done in other than flat terrain, add moisture and roll.

Estimated Cost of Mitigation Per Work Unit - $7.18 to $45.23/shoulder mile ($4.49 to $28.27/shoulder kilometer).

Repairing Curbs, Gutters, and Paved Ditches - Type II

Description - Curbs are structures at the edge of a highway which direct surface water flow as well as guide and restrain the movement of vehicles. A gutter is primarily a water carrier and may be constructed as an integral part of a curb. Paved ditches are used to carry large volumes of water down steep slopes or where highly erodible soils are encountered.

Repair practices are concerned primarily with patching deteriorated or damaged sections. Most curbs and paved ditches are constructed of portland cement concrete (PCC) although some are constructed with asphaltic concrete.

Paved ditches are particularly prone to collapse as the result of erosion from the sides and underneath. A slight settling or pulling apart at a joint creates a leakage point and a huge cavity can form in a matter of hours.

Repair involves first removing or breaking out the bad section, then the surface is formed as required, new material placed, exposed surface finished and, if PCC is used, sprayed with curing compound. Forms are removed at some later date.

Materials Used - Concrete, curing compound, asphaltic concrete.

Equipment Needed - Air compressor, concrete mixer, dump trucks, backhoe loader, and hand tools.

Estimated Cost Per Work Unit - $1.42 to $2.07/lin ft ($4.66 to $6.79/lin m).

Potential Water Quality Impact - Repairing curbs, gutters, and paved ditches may impact water quality from residual lime from concrete work, which could lead to changes in stream water chemistry, mainly pH.

Possible Mitigation Measures - Avoid this practice when the probability of precipitation is high, to reduce any runoff problems. Where refilling is necessary for lateral or vertical support of facility, nonerodible materials should be used.

Estimated Cost of Mitigation Per Work Unit - $0.14 to $0.31/lin ft ($0.46 to $1.02/lin m) when using nonerodible materials; otherwise, no increase in cost expected.

Bridge Surface Cleaning - Type II

Description - The cleaning of bridges involves sweeping; cleaning of pipe drains and gratings, scuppers, bridge seats; removing debris from expansion joints and waterway openings and materials used in snow and ice removal.

Sweeping of the deck surface, safety curbs, sidewalks, cleaning of longitudinal gutters and gratings is basic to the overall operation. The more difficult-to-reach areas involve the use of compressed air, water flushing, etc. Power brooms or street sweepers are on occasion found to be appropriate to major bridges following a winter when large quantities of abrasives were used in snow and ice removal. The greatest benefit is removal of chlorides from steel surfaces, which is best accomplished by water flushing. Flushing is an ideal way to open drains, scuppers, and to clean bridge seats. A combination of compressed air and hand tools is best in cleaning expansion joints.

Materials Used - Water.

Equipment Needed - Hand tools, dump trucks, air compressor, water tanks, and pumps.

Estimated Cost Per Work Unit - $95.96 to $118.87/each structure.

Potential Water Quality Impact - Bridge cleaning practices may introduce suspended solids and thus resuspend traffic-generated pollutants (e.g., lead, copper, zinc, nickel) into bodies of water, since many bridges span flowing streams.

Possible Mitigation Measures - Sweepings and other debris should not be cast over the side of the bridge. Instead, waste materials should be disposed of in designated fill areas not subject to erosion, or landfilled if necessary.

Estimated Cost of Mitigation Per Work Unit - $23.99 to $29.72/each structure.

Bridge Deck Repairs - Type II

Description - Bridge deck repair is a universal problem. The need for repair can result from traffic, climate, design or construction deficiencies, or a combination of all. It is one of the most sophisticated and most expensive maintenance practices.

Most deck repair is shallow in nature, 2 to 3 in (5 to 8 cm) deep, not full depth. The defective areas are sawed with a concrete saw, the bad material removed and the concrete and steel cleaned in the patch area. This cleaning involves the use of water, muriatic acid, and compressed air. Special grouts and mortars are used to coat the patch area, followed by the placing of fast-setting, high-strength concrete mixes. This may be sprayed with a curing compound if the deck surface is also the wearing surface. However, if the bridge has an asphaltic wearing course, the finish patch is completed as per "Pothole Patching."

Materials Used - Aggregates, quick setting cement, muriatic acid, curing compound, asphaltic concrete.

Equipment Needed - Air compressor, concrete saw, concrete mixer, water tank, dump trucks, welder.

Estimated Cost Per Work Unit - \$5.82 to \$7.05/ft^2 (\$64.67 to \$78.33/m^2).

Potential Water Quality Impact - Generation of suspended particulate matter may contribute to stream sedimentation. Use of acids presents the potential of altering receiving streams water chemistry, particularly pH.

Possible Mitigation Measures - The most practical mitigation is to avoid this practice when rainfall appears imminent, to reduce washoff of pollutants into receiving waters. Additionally, waste debris generated from this practice should be collected and disposed of properly, preferably landfilled.

Estimated Cost of Mitigation Per Work Unit - \$1.46 to \$1.76/ft^2 (\$16.22 to \$28.55/m^2) to landfill debris.

Mowing - Type II

Description - Mowing of grasses and other vegetation on highway right-of-ways is one practice that requires very little in the way of explanation. When to mow, where to mow, how often to mow, and how high to mow are functional considerations of terrain and adjoining land usage.

Materials Used - None.

Equipment Needed - Power mowers of various types and sizes.

Estimated Cost Per Work Unit - \$24.33 to \$32.21/acre (\$6,011 to \$7,959/km^2).

Potential Water Quality Impact - Mowing may possibly impact water quality in cases where cut vegetation enters a stream, thus increasing the biological oxygen demand (BOD) to the stream. This effect may decrease the dissolved oxygen available to support aquatic life.

Possible Mitigation Measures - If the swath of mowed materials within 33 ft (10 m) of a receiving water or drainageway left by sickle bar mowers is readily discernible after a period of approximately two days, it should be raked and removed. More frequent mowing to prevent large accumulations of cuttings near such areas is another method, although costs may be prohibitive.

Estimated Cost of Mitigation Per Work Unit - \$9.73 to \$16.11/acre (\$2,404 to \$3,980/km^2) for raking and removal.

Planting or Care of Shrubs, Plants, and Trees - Type II

Description - Planting is generally confined to late winter or early spring. Normally, seedling stock is used that is from 1 to 4 years of age. Thus, there is a very minimum of soil disturbance in their planting. Fertilizer and mulching are used sparingly.

A high percentage of the man-days spent in this practice is for trimming, spraying, mulching, and fertilizing of established specimens. Some removal is done because of vehicular damage, vandalism, disease, or to improve vehicular sight distance. This practice is not an ongoing every-day practice, but is done seasonally or as required.

Materials Used - Plants, shrubs, trees, mulch, fertilizer, chemical sprays.

Equipment Needed - Tank or knapsack sprayers, hand- or power-driven earth augers, brush chippers, trucks, hand tools.

Estimated Cost Per Work Unit - $8.32 to $12.41/man-hour.

Potential Water Quality Impact - The use of fertilizers presents the potential for increased nutrient loading to nearby streams. Chemical sprays (insecticides) used to control blight and insects may impact stream life through their toxic effects. Increased sedimentation from excavation activities associated with planting may impact nearby streams.

Possible Mitigation Measures - Fertilizers should be of the "slow-release" type. All insecticides should be approved and used according to label specifications. Additional mitigation may be achieved by using insecticides which have a relatively low potential for aquatic life impacts (see Appendix B). Care should be taken to minimize disturbance of soils and to prevent erosion.

Estimated Cost of Mitigation Per Work Unit - $2.08 to $3.72/man-hour.

Seeding, Sodding, and Fertilizing - Type II

Description - Seeding, sodding, and fertilizing are practices that are often overlooked in the rush to get on to other work. Once a slope or slip or slide is repaired, that final task of seeding or sodding may seem of little importance. Unless field reporting is incorrect, it would seem that these practices, which are one of the most important mitigating measures for many major maintenance practices, are often not done.

Seeding and sodding is mostly confined to vegetative areas that have been injuriously disturbed by some maintenance work. At times it is to cure some erosion problem of long standing; or perhaps an area has rejected attempts to establish a cover since the time of construction and another effort to do so is to be made.

Heavy application of fertilizers is confined to roadsides with very shallow top soil or soil types lacking in nutrients. In these cases, application helps to improve vegetative cover, promote soil stability, and reduce overall maintenance requirements.

Seeding requires a very light scarification of the soil, the seed is then applied, then the chemical fertilizer and lime (if needed), and finally a mulch or cover. On small areas practically all materials are applied by hand, using tools that one might use in lawn care. Larger areas warrant the use of the big power equipment, such as hydroseeders, mulch blowers, etc.

Materials Used - Grass seed, lime, chemical fertilizers, mulch.

Equipment Needed - Seeders, spreaders, harrows, tractors, trucks, and hand tools.

Estimated Cost Per Work Unit - \$14 to \$18.42/1,000 ft^2 (\$1.26 to \$1.66/1,000 m^2).

Potential Water Quality Impact - While seeding, sodding, and fertilizing have the potential for temporarily increasing the nutrient load to nearby streams and water courses, increase in turbidity is rather unlikely. Further, the water quality protection effect of establishing a vegetative cover should more than offset the temporary effects of the seeding or sodding activity.

Possible Mitigation Measures - Use of slow-release fertilizers is recommended. In addition, fertilizers should be used in a careful and controlled manner to avoid over-application. Soil analysis is recommended to determine the proper application rate.

Estimated Cost of Mitigation Per Work Unit - \$14.00 to \$18.42/1,000 ft^2 (\$1.26 to \$1.65/1,000 m^2) (i.e., may add up to 100 percent to cost).

Application of Abrasives - Type II

Description - Abrasives are applied where highway surfaces are covered with snow or ice in order to increase vehicular traction, thus reducing the hazard potential of the road surface. Generally, a sand or cinder abrasive is applied by dump trucks equipped with spreaders. The trucks travel along the road and may distribute a constant amount of abrasive, independent of truck speed, or may distribute an amount proportional to the truck's speed. In either case, the distributor may be adjusted to cover a 12 to 36 ft (3.7 to 11 m) width of the highway.

Materials Used - Sand and cinders.

Equipment Needed - Dump trucks and grit spreaders.

Estimated Cost Per Work Unit - $3 to $3.40/lane mile ($1.80 to $2.04/lane kilometer).

Potential Water Quality Impact - Fine particles of sand or cinder which are susceptible to transport via stormwater runoff may add to stream sedimentation, thus degrading aquatic life habitat. Further, the pulverization of larger particles by vehicular action may contribute to this process.

Possible Mitigation Measures - Use of abrasives on snow- and ice-covered highways is necessary for safety. Avoiding over-application of abrasive materials is probably the single most important factor in reducing potential water quality impacts. This may be achieved through proper calibration of equipment and training and supervision of personnel responsible for this practice. Also, abrasives containing a minimum of fine particles should be used, if available.

Estimated Cost of Mitigation Per Work Unit - $0.30 to $0.51/lane mile ($0.18 to $0.31/lane kilometer).

Care of Rest Areas - Type II

Description - Care of rest areas involves one or more of the following:

- Litter pickup
- Mowing
- Care of trees and shrubs
- Cleaning restrooms
- Repair and maintenance of picnic areas
- Pest control
- Maintaining sewage treatment systems

Materials Used - Soaps and detergents, insecticides, wood preservatives (pentachlorophenol), and fertilizer.

Equipment Needed - Chemical sprayers, mowers, and tank trucks.

Estimated Cost Per Work Unit - $13.75/man-hour.

Potential Water Quality Impact - Toxicity to aquatic life from use of insecticides, increased nutrient load to streams from phosphorus-containing detergents, and ineffective sewage treatment or disposal of sludge are possible adverse water quality impacts. As well, there is a potential toxicity to aquatic organisms from the use of wood preservatives.

Possible Mitigation Measures - Proper operation and maintenance of sewage treatment system or other septic system and disposal of sludge by approved methods will serve to effectively control the major source of water quality problems in rest area maintenance. Also, proper application and handling of insecticides is imperative to reducing potential water quality problems. Insecticides should be chosen according to the method presented in Appendix B.

Estimated Cost of Mitigation Per Work Unit - $1.38/man-hour.

Washing and Cleaning Maintenance Equipment - Type II

Description - Through normal usage, maintenance equipment becomes covered with and contaminated by a wide range of solids, liquids, and chemicals. Proper maintenance requires timely washing, cleaning, and repainting.

Trucks and spreaders are typically washed after every storm if the unit was used in ice and snow removal. Equipment used in herbicide or insecticide application is washed and cleaned prior to prolonged storage. This may occur in the maintenance yard or along the highway right-of-way. Trucks are washed at every normal service period or more often if heavy usage requires. Loaders are washed after every winter storm period. Much of the "off-road" or specialized equipment is not washed or cleaned on a regular basis, but only as required. Due to its type of use, much highway equipment is completely repainted or spot painted numerous times during its lifetime. This involves much scraping, grinding, and sanding.

Cleaning the equipment that is used in any type of asphalt paving requires the use of petroleum solvents, and cleaning of pavement, painting, and marking equipment requires the use of very strong solvents.

Spent solvents are disposed of in a variety of ways, ranging from spreading them along the maintenance yard fences or similar overland disposal along the highway to containment in drums and disposal in approved landfills.

Materials Used - Water, petroleum-based solvents, chemical cleaners, paints, detergents.

Equipment Needed - Hand tools, steam cleaners, power grinders, sand blasters.

Estimated Cost Per Work Unit - $12.29/unit.

Potential Water Quality Impact - Possible increase of suspended solids load to streams. Potential toxicity to aquatic life from improper disposal of spent solvents.

Possible Mitigation Measures - Maintenance equipment work should take place from wash racks and in proper cleaning areas, with properly maintained sediment traps and filters in place. Spent solvents should be collected and disposed of in a manner approved by the State agency charged with environmental protection authority.

Estimated Cost of Mitigation Measure Per Work Unit - $1.23/unit.

Bulk Storage of Motor Fuels - Type II

Description - Most maintenance organizations buy in bulk quantities and store their motor fuels (gasoline and diesel fuel). Underground storage tanks may develop leaks that go undetected.

Materials Used - Not applicable.

Equipment Needed - Not applicable.

Estimated Cost Per Work Unit - Not applicable.

Potential Water Quality Impact - Although this is not a maintenance practice in the true sense of the word, the ultimate effect can be detrimental to water quality. Contamination of groundwater, streams, and ponds are the major impacts expected.

Possible Mitigation Measures - Good recordkeeping of fuel dispensing is probably one of the best ways to detect leakage from underground fuel tanks.

Estimated Cost of Mitigation Per Work Unit - No increase in cost would be expected as fuel dispensing records are usually kept as part of routine accounting.

Disposal of Used Lubricating Oils - Type II

Description - The total of all motor vehicles and internal combustion engine driven equipment in any highway maintenance organization is sizable. The sheer number, along with more strict equipment maintenance policies by most governmental organizations, results in appreciable volumes of used motor oils.

Used motor oil disposal is either by sale to oil reclaimers or by dumping, the latter often taking the form of road oiling to control dust. If it is dumped into the nearest out-of-the-way depression or sprayed on road surfaces, a good portion of the oil may find its way into receiving waters.

Materials Used - Not applicable.

Equipment Needed - Not applicable.

Estimated Cost Per Work Unit - Not applicable.

Potential Water Quality Impact - Any unconfined petroleum product or its derivative can impact water quality. In addition, used motor oils contain significant amounts of lead, copper, nickel, and zinc, all of which present the potential for toxic effects to aquatic life.

Possible Mitigation Measures - Used motor oils should be stored in 55 gal (208 L) steel drums or larger tanks. Final disposal via approved landfills or to reclaimers are preferred methods.

Estimated Cost of Mitigation Per Work Unit - Landfill disposal would cost $0.18 to $0.22/gal ($0.05 to $0.06/L). Reclaimers typically pay $0.15 to $0.25/gal ($0.04 to $0.06/L)

MAINTENANCE PRACTICES WHICH HAVE NO PROBABLE IMPACT (Type III)

Blading Unpaved Surfaces - Type III

Description - Blading unpaved roadways is a very basic practice. The existing surface is smoothed and resurfaced by use of a motor grader or a steel drag pulled by a truck or tractor. Ideally, this work is done when moisture content is at optimum, although in practice this is not always possible.

Materials Used - Additional materials in the form of aggregates must be added from time to time.

Equipment Needed - Motor graders, drags, under-body truck-mounted blades.

Pothole Patching - Type III

Description - Potholes may be characterized as a deterioration of the road pavement to the extent that holes about 1 to 2 ft in diameter (0.3 to 0.6 m) are formed. Potholes often extend below the wearing surface, and sometimes through the base and subgrade layers. Pothole patching involves four steps:

- Clean - Remove loose material and square the edges with hand or air tools.
- Prepare - Dry the area and tack with a coating of liquid asphalt.
- Place - Place patching material in 2- or 3-in (5- to 8- cm) lifts (layers).
- Compact - Compact each lift with hand tools and do final compacting with roller or truck tires.

Materials Used - Liquid asphalt (emulsions or cutbacks); bituminous mixtures (hot); bituminous mixtures (cold); and aggregate.

Equipment Needed - Trucks, bituminous kettle or distributor, roller, picks, shovels, hand tampers, air compressor, and air tools.

Potential Water Quality Impact - Pothole-patching practices are not likely to have a major impact on water quality. Most materials removed in the cleaning phase are, for the most part, inert. Secondly, liquid bituminous materials used for tack are applied sparingly - less than 0.1 gal/yd^2 (0.3 l/m^2). Most of today's tack material used in this practice are emulsions of base asphalt, water, and a detergent. Further field studies conducted as part of this research project (see Volume II) indicate that water-soluble emulsions do not contain polynuclear aromatic hydrocarbons (PAHs), which are suspected of causing cancer. Thus, it may be concluded that pothole patching has no potential for serious harm to aquatic life or human health.

Surface Repairs - Type III

Description - Surface repair work is best described as machine-patching areas of pavement and berm surfaces with a bituminous mixture to correct rough or structurally weak pavement surfaces, rutting, pavement slab differential, and to maintain a good rideable surface until pavement is completely resurfaced. The actual repair might be full pavement width, half width, a long narrow strip, a wedge to build up a low edge, or correction of irregularities. Preparatory work is minimal and generally involves only some sweeping and removal of any loose material. A bituminous tack coat is then applied. Next, a premixed bituminous patching material is placed by a paver or motor grader and then compacted with a roller.

The use of liquid asphalts is not likely to impact water quality, as inferred from research conducted as part of this project (see Volume II).

Materials Used - Liquid asphalt, bituminous mixture.

Equipment Needed - Hand tools, grader or paver, bituminous distributor, roller, dump trucks, water tank, and power broom on major jobs.

Filling and Sealing Joints and Cracks - Type III

Description - The proper maintenance of any pavement requires the cleaning and filling of joints and sealing of cracks. Without such maintenance bituminous or concrete pavement will readily deteriorate due to excessive cracking or joint failure.

The very nature of this practice sounds extremely simple. Water and debris are cleaned and removed from cracks and joints and the crack or joint is filled and made flush with surface. Cleaning is accomplished by compressed air discharged through a restricted nozzle so as to give a blasting effect. Ideally, the crack would be plowed out with a sharp point so as to leave a V-shaped opening about 1-in (2.5 cm) deep and 1/2-in (1.3 cm) wide. This is extremely difficult to do and very expensive, so it is seldom done. However, it can be done rather easily in a joint since the joint was formed at the time of construction by a sawing or grooving which produces a rectangular opening of some size.

After cleaning, the crack or joint is filled with of liquid asphalt, or a cold rubber filler is used that is applied much as one would with a giant calking gun. There are other materials but the two mentioned are the most common.

The final step is to apply some blotting material such as sand if traffic and temperature demands. Narrow strips of plain kraft paper are put down over the cold, rubber-filled joints.

Materials Used - Liquid asphalt, cold rubber, sand, kraft paper.

Equipment Needed - Air compressor, asphalt kettle or bituminous distributor, trucks, pouring pots, trucks, and hand tools.

Pavement Jacking - Type III

Description - The maintenance practice of pavement jacking is simply the lifting of settled portland cement concrete pavements to their proper elevation. The more expeditious method, although not necessarily correct, is to fill the depression with asphaltic concrete. It is quicker, less expensive, and less disruptive to traffic.

In this maintenance activity, a series of holes about 2 to 2-1/2 in (5 to 6.5 cm) in diameter are drilled on a predetermined pattern, and a thick slurry of portland cement and agricultural lime is injected under medium pressure. The pavement is lifted up, the surplus water is dissipated, and the remaining ingredients solidify. The pavement is thus returned to its "as built" elevation. Probably less than 10 percent of the materials are left upon the pavement and shoulders to be carried away by traffic or the flushing action of rainfall.

Materials Used - Portland cement, lime, and fire clay; on occasion, select soils are used in lieu of lime.

Equipment Needed - Air compressor, trucks, mortar or concrete mixer, positive displacement pump, pneumatic drill, wood plugs.

Planing Pavements - Bituminous and Concrete - Type III

Description - Planing bituminous pavements using heat or by mechanical means is a well-established practice. Planing of portland cement concrete pavements reflects a more recent state-of-the-art practice.

The principal binding agent in a bituminous pavement is thermoplastic, so if its temperature is elevated to about 250 to 300 °F (121 to 149 °C) it no longer binds the aggregate and the whole pavement mass crumbles. In this condition, the asphalt cement can be readily moved about with a rake, shovel, or grader. Leveling the pavement by scraping off the high spots, filling in the low spots, and rolling will result in a smooth surface.

To offset the high fuel costs of heat planing, high-speed cutters are used to chip off the offending high spots and elevate the cuttings into a trailing dump truck.

A machine now available is similar in operation to the bituminous planer, but with an added feature that allows it to plane portland cement concrete pavement. Since portland cement concrete is much harder, it requires many more diamond tipped cutting teeth which must be run under a constant stream of water. This machine produces fine cuttings instead of chips. The machine lifts the water and abraded material from the pavement and deposits it on the roadside.

Materials Used - Water.

Equipment Needed - Hand tools, trucks, graders, roto mills, water tankers, rollers.

Bridge Joint Repairs - Type III

Description - Bridge joints are either "fixed" or "expansion." The "expansion" is the more troublesome of the two. Traffic imposes repetitive stresses, and the intrusion of dirt and debris tend to block or impede the correct joint action. The joint metals crack or break or pull loose from the anchors embedded in the concrete.

To repair, first, all loose, disintegrating material is removed from the joint area and the area is squared up. Next, the joint angle is welded to the embedded steel or anchors. Then, a special high early strength concrete is mixed and vibrated to the level of the concrete pavement surface, and a curing compound is applied. If the bridge has an asphalt wearing course, patch is placed in an approved fashion.

Materials Used - Structural steel, reinforcing steel, aggregates, special cements, curing compound, and asphaltic concrete where required.

Equipment Needed - Air compressor, concrete saw, welder, concrete mixer, water tank, dump trucks.

Superstructure Repair - Type III

Description - Bridge superstructure repair practices can involve replacement or straightening of steel, concrete repair, railing repair, or painting. Generally, such practices are needed for steel truss bridges as a result of age, accident, or overload. Railings and overhead bracing also are frequently damaged in accidents.

Patching of deteriorated members is done by welding in new steel; broken members are rewelded, reriveted, or rebolted. The first step is to remove or prepare areas to be repaired. Next, material is installed or concrete is placed followed by painting or curing, if necessary.

Materials Used - Structural steel, concrete, railing, cement, paint.

Equipment Needed - Air compressor, welder, trucks, hand tools.

Cleaning Pavement - Type III

Description - This activity involves the removal of dirt and debris from paved surfaces, berms, along curbs and gutters and along median barriers. It also includes removal of material resulting from slides, cargo spills, and vehicular accidents (excluding hazardous materials spills).

Materials Used - As required.

Equipment Needed - Brooms, shovels, trucks, power-driven rotary broom, loader, and mechanical sweeper.

Guardrail Repair - Type III

Description - The first step in repairing guardrails is to remove the damaged posts and sections of rail. Next, new post holes are drilled, if treated-wood posts are used, or steel posts are driven in such a manner to avoid battering or distorting posts. Rail elements are then fastened to the posts to form a smooth, continuous installation.

Materials Used - Steel or wooden posts, rails, bolts, fittings, spacers, etc.

Equipment Needed - Post-hole digger, pile-driver, saws, wrenches, etc.

Snow Plowing - Type III

Description - Snow plowing is a very costly, but necessary practice, one that has no practical alternative. The only vegetation that is ever disturbed is the result of an errant snow plow or a novice operator.

Plowing unpaved surfaces does create loss of road aggregate. The most modern equipment in the hands of the most skilled operator cannot prevent this. It should be kept in mind that plowing snow-covered highways is carried out in a semi-emergency situation and under most adverse conditions.

Crash Attenuator Repairs - Type III

Description - Repair of crash attenuator devices involves the removal of broken containers, sweeping up sand (if it is that type), reassembly or replacement of the individual units, and refilling with the proper material.

Materials Used - Replacement attenuators, sand, calcium chloride solution.

Equipment Needed - Brooms, shovels, loaders, dump truck.

Snow Fence Installation and Removal - Type III

Description - Of all maintenance practices, placement of snow fences has to be one of the least disruptive. Snow fencing comes in 4-ft (1.2 m) high, 50-ft (15.2 m) rolls, supported every 10 ft (3.04 m) by lightweight steel drive posts and attached with soft wire ties. The posts are driven into the ground so there is no excavation or deposits of loose earth. It is installed in late October or early November when the ground is typically still firm so the lightly laden trucks leave no wheel ruts. Some snow fences may remain left in place throughout the year. Other snow fences may require removal in the spring.

Materials Used - Steel post, rolls of snow fence, and tie wires.

Equipment Needed - Trucks, post drivers, wire cutters.

Highway Lighting - Type III

The maintenance of a highway lighting system necessitates little or no disturbing of surface features. In nearly all cases, the electrical power is carried underground through a system of pipe conduits and junction boxes.

Errant vehicles frequently knock over light poles. Relamping is done either on a time-elapse basis when all lamps in a system are replaced as they approach the limit of their designed life expectancy, or only as they burn out.

Turning on and off is by photoelectric cell. The underground circuitry is subject to the normal hazards associated with excavations, post driving, weather extremes, slope erosion, etc. Poles are either aluminum or galvanized steel although many of the early installations used painted steel poles. They were seldom or never repainted. So, unlike a bridge, painting is not a factor.

Flat Sheet, Side-mounted, and Overhead Sign Maintenance - Type III

Description - Sign maintenance is needed to preserve the readability and reflectivity of the various signs along the highway which have been erected to control traffic, identify routes, and the like. This involves replacing letters and some metalwork from time to time.

Washing, the major activity related to this practice, is done primarily to increase the reflectivity of a sign, particularly in darkness. This is performed by scrubbing the sign with a detergent and water solution, followed by rinsing.

Materials Used - Detergent and water.

Equipment Needed - Ladder or bucket truck, hoses, brushes.

Pavement Marking - Type III

Description - Paint (white and yellow) glass beads, thinners, plastic marking materials, and adhesives are commonly used to mark pavement. The quantities of traffic paint and glass beads required are quite appreciable. The amount of thinner mixed into the paint is normally less than 2 percent.

Some of the solvents used to clean tanks and spray equipment is of exotic formulation and generally highly volatile. At least once a year striper tanks and transport tanks are cleaned with caustic soda to remove paint build-up not removed by the daily dosage of cleaning solvents.

Much of the paint used today is very fast-drying, so a sudden rainstorm or traffic action does not impact water quality. Some paint is even applied at elevated temperatures, hence the expression "hot paint."

Bulk Storage of Nonfuel Materials - Type III

Description - Bulk materials stored in the open by highway agencies include sand, gravel, cinders, salt, wood products, culvert pipe, etc. Other materials are usually stored under roof. Fuel storage is considered under "Bulk Storage of Motor Fuels," Class II.

Mineral aggregates such as sand, gravel, and limestone are unlikely to impact water quality. Cinders or abrasives which are often treated with chlorides to prevent freezing, along with road salt stored in the open, may cause an impact in some cases. Generally, if storage facilities are well constructed and maintained, water quality impacts are not likely.

Roadside Litter Control and Disposal - Type III

Description - Litter and debris deposited within the highway right-of-way are collected periodically. Collection usually involves deploying litter control crews and trucks to police areas adjacent to the highway. The collected trash is then hauled to a landfill for disposal.

Equipment Needed - Dump truck, litter collection tools and bags.

CONTACTS FOR FURTHER INFORMATION

Generally, most State highway departments perform tests on current or potential highway maintenance and repair materials. Ultimately, this applied research helps determine or develop materials and methods which reduce highway maintenance needs, while in addition, providing cost-effectiveness of maintenance operations.

Agencies, organizations, and companies that, at various times, have researched and developed highway maintenance technologies were identified during this study. Table 4 lists groups which have conducted research and development of highway maintenance technology, their specific area of research, and references to representative reports. This compilation provides highway maintenance personnel with a rapid referral for specific questions on problems related to applications of highway maintenance practices.

Table 4. Agencies, organizations, and companies with past and present involvement in research and development of highway maintenance technologies.

Agency, organization, or company	Area(s) of research and development	Reference
	Highway surfaces	
The Asphalt Institute College Park, Maryland	Asphaltic pavement maintenance materials and techniques Asphalt overlays Petroleum asphalt, coal-tar pitch and road tar	The Asphalt Institute, 1983 The Asphalt Institute, 1981 Puzinauskas and Corbett, 1978
California Department of Public Works Victorville, California	Asphalt recycling	Aguirre, 1980
California Department of Transportation, Office of Transportation Laboratory Sacramento, California	Coatings, sealants, and pavement markers	Chatto et al., 1976
Ecole Polytechnique Montreal, Quebec	Asphalt road maintenance	Bosisio, Spooner and and Granger, 1974
IIT Research Institute Chicago, Illinois	Pavement planing	Hilaris and Bortz, 1980
Pennsylvania Department of Transportation Harrisburg, Pennsylvania	Asphalt overlays	Klucher, 1973
Portland Cement Association Minneapolis, Minnesota	Portland cement concrete overlays	Schnoor and Renier, 1979
Texas Department of Highways and Engineering Austin, Texas	Resurfacing concrete pavement	Billingsley, 1966
Transportation Research Board, National Academy of Sciences Washington, D.C.	Asphalts, aggregates, mixes, and stress-absorbing membranes	Transportation Research Board, 1976
Transportation Research Board, National Academy of Sciences Washington, D.C.	Joint repair	Bryden, McCarty, and Cocozzo, 1976
Transportation Research Board, National Academy of Sciences Washington, D.C.	Pavement planing	Vyce and Nittinger, 1977
Transportation Research Board, National Academy of Sciences Washington, D.C.	Surface repair and maintenance techniques	Byrd, Tallamy, MacDonald, and Lewis, Inc. 1975
University of Illinois, Department of Civil Engineering, Transportation Research Laboratory Chicago, Illinois	Concrete pavement patching	Maxey, Darter, and Smiley, 1979
University of Texas, Center for Highway Research Austin, Texas	Concrete-polymer materials	Fowler and Paul, 1979
Virginia Highway Research Council Charlottesville, Virginia	Planing concrete pavement	Creech, 1974

Table 4. Agencies, organizations, and companies with past and present involvement in research and development of highway maintenance technologies. (Continued)

Agency, organization, or company	Area(s) of research and development	Reference
	Structural steel	
Griffiths Bros. & Co. (London) Ltd., Armour Works Wednesfield, Wolverhampton, England	Anti-corrosive treatments for structural steel	Claxton and Carter, 1969
Maine Department of Transportation, Materials and Research Division Bangor, Maine	Structural steel paint	Leyland and Hsu, 1979
Oregon State Department of Transportation Salem, Orgeon	Paint formulations	Hart and Davis, 1973
U.S. Department of Transportation, Offices of Research and Development Washington, D.C.	Coatings for structural steel	Bruno and Keane, 1981
	Vegetation control and maintenance	
Broward County Highway Department Florida	Remote location refillable water tankers	Anon., 1974
Florida Department of Transportation Tallahassee, Florida	Herbicide application techniques	Morris, 1981
Hercules, Inc. Wilmington, Delaware	Herbicide application techniques	Feddersen, 1970
Louisiana Department of Transportation and Development Baton Rouge, Louisiana	Vegetation control-chemical spraying	Pourciau, 1980
Massachusetts Department of Public Works Boston, Massachusetts	Vegetation control	Anon., 1978b
Pennsylvania Department of Transportation Harrisburg, Pennsylvania	Vegetation control	Anon., 1973
Pennsylvania Department of Transportation Harrisburg, Pennsylvania	Vegetation control-chemical spraying	Ross, 1981
Purdue University, Department of Biological Sciences and Joint Highway Research Project Lafayette, Indiana	Vegetation control-chemical spraying	Morré, 1978
Wisconsin Department of Natural Resources Madison, Wisconsin	Vegetation control	Rusch, Thompson, and Kabat, 1980

Table 4. Agencies, organizations, and companies with past and present involvement in research and development of highway maintenance technologies. (Continued)

Agency, organization, or company	Area(s) of research and development	Reference
	Bridge maintenance	
California Department of Transportation, Office of Transportation Laboratory Sacramento, California	Coatings on coastal steel bridges	Rooney, Woods, and Shelly 1970
Colorado Department of Highways, Division of Transportation Planning Denver, Colorado	Bridge deck protective system	Steere and Swanson, 1980
Howard, Needles, Tammen and Bergendoff Newark, New Jersey	Bridge deck protective systems	Riley, 1967
Massachusetts Department of Public Works Boston, Massachusetts	Protection of concrete bridge decks by membrane waterproofing	Hagenbuch, 1968
New York State Department of Transportation Albany, New York	Bridge deck membranes	Chamberlin, Irwin, and Amsler, 1977
Port of New York New York	Bridges (general)	Zitelli, 1972
Texas A&M University, Texas Transportation Institute College Station, Texas	Bridge deck maintenance	Moore, 1973
Transport and Road Research Laboratory Crowthrone, England	Corrosion performance of steel in bridges	McKenzie, 1978
Transportation Research Board, National Academy of Sciences Washington, D.C.	Bridge deck repair	Manning and Ryell, 1980
West Virginia University, Department of Civil Engineering Morgantown, West Virginia	Grid decks for bridge floors	GangaRao, 1980
Transportation Research Board, National Academy of Sciences Washington, D.C.	Waterproof membranes	Van Til, Carr, and Vallerga, 1976
U.S. Department of Transportation, Offices of Research and Development Washington, D.C.	Bridge painting	Niessner, 1979

Table 4. Agencies, organizations, and companies with past and present involvement in research and development of highway maintenance technologies. (Continued)

Agency, organization, or company	Area(s) of research and development	Reference
	Safety devices and structures	
Oregon State Department of Transportation Salem, Orgeon	Impact attenuators	Bothman, 1972
Texas Department of Highways and Engineering Austin, Texas	Guardrail protective coatings	Anon., 1978a
U.S. Department of Transportation, Offices of Research and Development Washington, D.C.	Highway lighting maintenance	Hogan, 1971
Wyoming Highway Department Cheyenne, Wyoming	Snow fence design	Anon., 1979
	Miscellaneous	
California Department of Transportation, Office of Transportation Laboratory Sacramento, California	Biological pest control	Cassidy, 1978
Virginia Polytechnic Institute and State University Blacksburg, Virginia	Erosion control	Wright, Perry, and Blaser, 1976

GLOSSARY

Bent: An undersupport placed at the midpoint of a simple beam span to increase its capacity.

Benthic: Relating to the bottom of a body of water.

BOD: See Biochemical Oxygen Demand.

Biochemical Oxygen Demand: The quantity of oxygen required under specific test conditions by certain organic and oxidizable waterborne substances to be broken down (oxidized) by biological means.

Cellular Retaining Wall: A hollow box-like structure filled with earth or rock to give great mass; possesses the physical properties to function as a modified gravity retaining wall.

Cutback: A mixture of asphalt and petroleum solvents (distillates), produced by blending those materials in such proportions as to give a readily handled fluid mass over a wider range of temperatures and field conditions.

Dissolved Oxygen (DO): The quantity of oxygen dissolved in water or other liquid, usually expressed in milligrams per liter or percent saturation.

Eutrophication: The process whereby a water body matures from a nutrient-poor to nutrient-rich system, with characteristic changes in water quality, fish, and other aquatic life.

LC_{50} (median lethan concentration): A statistical estimate of the concentration of a test material necessary to cause death in 50 percent of a test population within a given time, typically 24, 48, or 96 hours.

PAH: See Polynuclear Aromatic Hydrocarbon.

pH: A measure of acidity and alkalinity on a scale of 0 to 14, where 7 is neutral, values less than 7 indicate acidity, and values greater than 7 indicate alkalinity.

Plant Nutrients: Typically refers to nitrogen and phosphorus contained in fertilizers.

Polynuclear Aromatic Hydrocarbon: Any one of several compounds derived from incomplete combustion of coal, coal-tars, and other petroleum-based products.

Retention Basin: A manmade depression or impoundment to retain surfaces runoff waters sufficiently long to allow for the dropping of at least the larger suspended solids.

Riprap: A durable material, usually stone, placed on embankment slopes to prevent erosion.

Rope-wick: A long, slender, and flexible perforated tube wrapped with an absorbent material used as a means of applying herbicides by direct contact.

Roto Mill: The trade name for a mobile pavement profiling device that acts much the same as a milling machine through the action of its multitoothed cutting head. Capable of cutting to close tolerances.

Rutting: The saucer-shaped depression created in the wheel-patch area of a pavement by the passage of vehicles.

Sedimentation: The process whereby particulate matter is deposited or settles to the bottom of a stream or channel.

Suspended Solids: Solids such as silt, clay, or organic matter that are in suspension in water, and which are largely removable by filtering.

Surfactant: An agent which tends to reduce the surface tension of the solvent (primary liquid) to the degree that it better adheres or sticks to the target plant.

Turbidity: A measure of the reduction of transparency of a water body due to the presence of particulate matter.

Wetland: Areas such as swamps, bogs, or tidal flats containing high soil moisture.

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APPENDIX A

METHOD FOR SELECTING "ENVIRONMENTALLY PREFERABLE" HERBICIDES FOR ROADSIDE VEGETATION CONTROL

The impact a herbicide will have on an aquatic environment depends on (1) how toxic the chemical is to aquatic life, (2) how much of the chemical applied to the roadside can be expected to reach the water (via overland runoff), and (3) the persistence of the chemical in the water. The method presented in this appendix is a way of ranking each herbicide based on these factors. By comparing all herbicides in a common manner, the maintenance engineer and vegetation management specialist are able to select the herbicide that will do the best job of controlling the roadside vegetation with the least threat to adjacent aquatic environments.

One common method by which the aquatic toxicity of a chemical may be evaluated is to determine, through appropriate bioassay procedures, the concentration which is lethal to 50 percent of a test population (e.g., fish), otherwise known as the median lethal concentration, or simply, LC_{50}. However, the effects of chemicals on aquatic life also depend on the length of exposure. Therefore, LC_{50} values must include time when expressing bioassay results. For example, the 96-hour LC_{50} is the concentration of a chemical which is lethal to 50 percent of the test organisms in 96 hours. The lower the LC_{50} value, the more toxic the chemical; and thus, LC_{50} values must be judged relative to other LC_{50} values.

Table 5 provides a listing of common names and synonyms for pesticides listed in this appendix. Actual seasonal loss rates, averaged from field measurements, were available for 13 of the herbicide formulations listed in Table 6, taking seasonal loss rate, which takes into account soil mobility properties of the herbicide such as leachability and adsorptive characteristics, is a property of the specific formulation of the herbicide and not simply its chemical nature. When no loss rates were available for a given herbicide, the loss rate was estimated based on the formulation alone (Wauchope, 1978). Obviously, calculations using these estimations will be less accurate as they will not take into account the mobility of the individual herbicides in the soil.

The application rate reported represents the extreme high and low dosages recommended by the manufacturers. This factor should represent, to a certain extent, the effectiveness of the herbicide for the use specified, therefore, making comparison of herbicides having different application rates valid. The estimated seasonal loss of each herbicide was derived by multiplying the application rate (usually a range) by the seasonal loss rate.

Dividing the estimated seasonal loss rate, converted to milligrams per square meter, by the lowest reported 96-hour LC_{50} for the herbicide, yields a ratio value which is indicative of the herbicides potential for impacting water quality impactfulness of the herbicide (see Table 7). The higher the ratio value, the more likely the herbicide is to have aquatic life impacts based on its (1) toxicity, (2) seasonal loss rate, and (3) application rate. This value does not take into account the persistence of the chemical once it reaches the waterway nor does it express any actual in-stream or runoff concentration. The latter would require site-specific values: actual precipitation and stream volume measurements. The ratio value does, however, give a common point of comparison for all or most of the herbicides available to the maintenance engineer. This method permits the highway engineer to consider most of the relevant factors connected with herbicide selection (i.e., toxicity, leachability, formulation, application rate, and seasonal loss rate), to thereby select the chemical which will best suit his needs as well as being least dangerous to the aquatic environment.

Below is an example using the above method of herbicide selection. A worksheet is provided on the following page for use by the highway agency vegetation management specialist.

<u>Example</u>

Objective = <u>total vegetation control</u>

Herbicide now in use = <u>Atrazine</u>

Formulation = <u>wettable powder</u>

Ratio value = <u>100 to 600</u>

Alternative herbicide = <u>Aminotriazole</u>

Formulation = <u>wettable powder</u>

Ratio value = <u>0.14 to 2.8</u>

Work Sheet

Objective = ______________________

Herbicide now in use = ______________

Formulation = ____________________

Ratio value = ____________________

Alternative herbicide = ____________

Formulation = _____________________

Ratio value = _____________________

Table 5. Index listing of common names and synonyms for pesticides used by highway maintenance personnel on roadsides in the United States.

-A-

Aatrex, see ATRAZINE
Aatrex-Nine-O, see ATRAZINE
Acarin, see DICOFOL
ACEPHATE
Amaize, see DINOSEB
Amcide, see AMMATE
Amdon, see PICLORAM
AMINOTRIAZOLE
Amitral, see AMINOTRIAZOLE
Amitrole, see AMINOTRIAZOLE
Amizol, see AMINOTRIAZOLE
AMMATE
Ammate X, see AMMATE
Ammonium sulfonate, see AMMATE
Amoxone, see 2,4-D
AMS, see AMMATE
Ansar, see MSMA
Ansar 529, see MSMA
Ansar 8100, see DSMA
Aquacide, see DIQUAT
Aqua Kleen, see 2,4-D
Aquazine, see SIMAZINE
Asilan, see ASULAM
ASULAM
Asulox, see ASULAM
ATA, see AMINOTRIAZOLE
Atazinax, see ATRAZINE
Atranex, see ATRAZINE
Atratol A, see ATRAZINE
ATRAZINE
Azolan, see AMINOTRIAZOLE

-B-

Banex, see DICAMBA
Banvel, see DICAMBA
Basfapon, see DALAPON
Basinex P, see DALAPON
Basudin, see DIAZINON
Batazina, see SIMAZINE
Bitemal, see SIMAZINE
Bolls-Eye, see CACODYLIC ACID
Borlin, see PICLORAM
Borolin, see PICLORAM
BROMACIL
Brominal, see BROMOXYNIL
Brominil, see BROMOXYNIL
BROMOXYNIL
Bronate, see BROMOXYNIL
Brulan, see TEBUTHIURON
Buctril, see BROMOXYNIL
Bueno, see MSMA

-C-

CACODYLIC ACID
Candex, see ATRAZINE
CARBARYL
Carbax, see DICOFOL
Carbophos, see MALATHION
Carpolin, see CARBARYL
Casoron, see DICHLOBENIL
Cekuzina-S, see SIMAZINE
Cekuzina-T, see ATRAZINE
CF-125, see CHLOFLURENOL
Chemathion, see MALATHION
Chipco Crab Kleen, see DSMA
Chloflurecol, see CHLOFLURENOL
CHLOFLURENOL
Chlorfenac, see FENAC
Chlorflurecol, see CHLOFLURENOL
Clarosan, see TERBUTRYN
Clout, see DSMA
Crotilin, see 2,4-D
Curbiset, see CHLOFLURENOL
Cygon, see DIMETHOATE
Cythion, see MALATHION

-D-

2,4-D
Dacamine, see 2,4-D
Daconate, see MSMA
DALAPON
Dal-E-Rad 70W, see MSMA
Dal-E-Rad 100, see DSMA
Daphene, see DIMETHOATE
Dazzel, see DIAZINON
DCMU, see Diuron
De-Cut, see MALEIC HYDRAZIDE
De-fend, see DIMETHOATE
Demos-L40, see DIMETHOATE
Denapon, see CARBARYL
De-Sprout, see MALEIC HYDRAZIDE
Devrinol, see NAPROPAMIDE
Dextrone-X, see PARAQUAT
Dianat, see DICAMBA
Diazide, see DIAZINON
DIAZINON
Diazital, see DIAZINON
Diazol, see DIAZINON
DICAMBA
Dicarbam, see CARBARYL
DICHLOBENIL
Dichlorfenidim, see DIURON
DICOFOL
Dilic, see CACODYLIC ACID
DIMETHOATE
Dimethogen, see DIMETHOATE
DINOSEB
DIQUAT
Diquatbromide, see DIQUAT
Dirimal, see ORYZALIN
DIURON
DMA-4, see 2,4-D
DMDT, see METHOXYCHLOR
DMU, see DIURON
Dowpon, see DALAPON
DSMA
Duphar, see TETRADIFON
Du-Sprex, see DICHLOBENIL
Dynex, see DIURON

-E-

Embark, see MEFLUIDIDE
Emmatos, see MALATHION
Erase, see CACODYLIC ACID
Esteron, see 2,4-D

Table 5. Index listing of common names and synonyms for pesticides used by highway maintenance personnel on roadsides in the United States. (Continued)

Table 5. Index listing of common names and synonyms for pesticides used by highway maintenance personnel on roadsides in the United States. (Continued)

Source: Thomson, 1981a-b; Thomson, 1982.

Table 6. Method for assessing the potential water quality impact of herbicides used in highway maintenance of vegetated rights-of-way.

Herbicide	Use	Formulation[a]	Application rate (lb/acre)[b]	Seasonal loss rate (%)	Estimated[c] seasonal loss (lb/acre)	Lowest[d] reported 96-h LC_{50} (mg/l)	Relative impact Total loss / 96-h LC_{50}
2,4-D (salt)	General broadleaf weed control	S	0.25-4.00	0.2[e]	0.0005-0.0080	0.30	0.19-3.0
2,4-D (ester)	General broadleaf weed control	EC	0.25-4.00	0.5[e]	0.0013-0.020	0.24	0.61-9.3
Aminotriazole	Total vegetation control	WP	1-20	5[f]	0.05-1.00	40.5	0.14-2.8
		S	1-20	0.5[f]	0.005-0.10	40.5	0.014-0.28
Ammate	Brush and weed control	SP	30-190	0.5[f]	0.15-0.95	825	0.02-0.13
Asulam	Perennial grass control	S	2-7	0.5[f]	0.01-0.035	No data	--
Atrazine	Total vegetation control	WP	10-60	3.2[e]	0.32-1.92	0.36	100-600
Bromacil	Total vegetation control	WP	3-30	5[f]	0.15-1.50	56.7	0.30-3.0
Bromoxynil	Broadleaf weed control	EC	0.25-0.50	1[f]	0.0025-0.0050	40.5	0.007-0.014
Cacodylic acid	Total vegetation control	S	2.5-7.5	0.5[f]	0.0125-0.0375	17.0	0.082-0.25
Chloflurenol	Growth regulator	EC	2-35	1[f]	0.02-0.35	6.7	0.33-5.9
Dalapon	Perennial grass control	SP	0.27-20	0.5[f]	0.0038-0.10	76	0.006-0.15
Dicamba	Brush and weed control	EC	0.25-8.0	1[f]	0.0025-0.080	28	0.010-0.32
		S	0.25-8.0	0.5[f]	0.0013-0.040	28	0.005-0.16
Dichlobenil[g]	Selective weed control	WP	1.5-8.0	5[f]	0.075-0.40	5.7	1.5-7.9
Dinoseb	Broadleaf weed control	S	1-12	0.5[f]	0.005-0.060	0.036	16-187
Diquat[g]	Total vegetation control	S	1-2	0.5[f]	0.005-0.010	9.96	0.056-0.12

(Continued)

Table 6. Method for assessing the potential water quality impact of herbicides used in highway maintenance of vegetated rights-of-way. (Continued)

Herbicide	Use	Formulation[a]	Application rate[b] (lb/acre)	Seasonal loss rate (%)	Estimated[c] seasonal loss (lb/acre)	Lowest[d] reported 96-h LC_{50} (mg/l)	Relative impact Total loss / 96-h LC_{50}
Diuron	Selective and total weed control	WP	0.5-100	5[f]	0.025-5	16.0	0.18-35.0
		S	0.5-100	0.06[e]	0.0003-0.06	1.4	0.024-4.80
DSMA	Crabgrass and other weed control	SP	2-4	0.5[f]	0.01-0.02	12.2	0.092-0.18
Fenac	Weed control and soil sterilant	S	2-15	1.5[e]	0.03-0.23	6.1	0.56-4.1
Fenavar	Temporary soil sterilant	S	--	--	--	--	--
Fosamine	Brush control/ growth suppressant	S	6-12	0.5[f]	0.03-0.06	No data	--
Glyphosate	Annual weed control	S	0.50-2	0.5[f]	0.0025-0.01	2.3	0.12-0.49
	Perennial weed control	S	2-4	0.5[f]	0.01-0.02	2.3	0.49-0.97
Hexazinone	Short term broadleaf control	SP	2-5	0.5[e]	0.01-0.025	100	0.01-0.028
	Seasonal broadleaf control	SP	6-12	0.5[e]	0.03-0.06	100	0.034-0.067
Maleic hydrazide	Growth regulator	WP	0.75-3.00	5[f]	0.038-0.15	No data	--
		EC	0.75-3.00	1[f]	0.0075-0.030	No data	--
Mefluidide	Growth suppressant	S	0.25-2.0	0.5[f]	0.0013-0.0050	No data	--
MSMA	Selective control of grasses	S	2-5	1.2[e]	0.024-0.060	12.2	0.22-0.55
Napropamide	Selective weed control	WP	1-8	5[f]	0.050-0.40	No data	--
	Selective weed control	EC	1-8	1[f]	0.01-0.08	No data	--
Oryzalin	Selective control of grasses	WP	0.75-2.0	5[f]	0.038-0.10	3.14	1.36-3.57
Oxadiazon	Selective broadleaf control	WP	1-4	5[f]	0.05-0.20	0.83	6.75-27.0
		EC	1-4	1[f]	0.01-0.04	0.83	1.35-5.40
Paraquat	Total control of weeds and grasses	S	0.50	5[e]	0.029	13.0	0.25

(Continued)

Table 6. Method for assessing the potential water quality impact of herbicides used in highway maintenance of vegetated rights-of-way. (Continued)

Herbicide	Use	Formulation[a]	Application rate[b] (lb/acre)	Seasonal loss rate (%)	Estimated[c] seasonal loss (lb/acre)	Lowest[d] reported 96-h LC_{50} (mg/l)	Relative impact Total loss / 96-h LC_{50}
Picloram	Broadleaf control	EC	0.25-8.0	1.0[e]	0.0025-0.08	1.4	0.20-6.41
Pramitol	Total vegetation control	EC	10-60	1[f]	0.10-0.60	2.94	3.81-22.9
		WP	10-60	5[f]	0.50-3.0	2.94	19.1-114
Pronamide	Selective weed control	WP	0.5-2.0	5[f]	0.025-0.10	No data	--
Simazine	Selective weed control	WP	1-4.0	3.5[e]	0.035-0.14	0.40	9.81-39.2
	Total vegetation control	WP	5-40	3.5[e]	0.175-1.40	0.40	49.0-392
Tebuthiuron	Total vegetation control	WP	0.75-8.0	5[f]	0.038-0.40	No data	--
Terbutryn	Broadleaf weed control	WP	0.80-2.50	5[f]	0.040-0.13	0.82	5.47-17.1
Trifluralin	Broadleaf and other weed control	EC	0.50-2.0	0.22[e]	0.0011-0.0044	0.009	13.7-54.8
Ureabor	Total, long term vegetation control	G	400-6,000	1[f]	4.0-60	100	4.48-67.3

[a] Formulation: WP - wettable powder; S - solution; EC - emulsifiable concentrate; SP - soluble powder; G - granules.

[b] Application rate represents extreme high and low dosages based on manufacturer information; average dosages used should fall in between these rates.

[c] Metric conversion factor: (lbs/acre) x (112.1) = (mg/m^2)

[d] 96-h LC_{50} values reported for fish species only.

[e] These loss rates are averages of actual field measurements of this herbicide specifically.

[f] These loss rates are averages based on formulation alone; no data availabe for specific herbicide.

[g] These herbicides are also used for aquatic weed control; these values do not reflect aquatic applications.

Table 7. Herbicides rank ordered by the lowest relative impact value.[a]

Herbicide	Formulation[b]	Relative impact value	Use
Atrazine	WP	100-600	Total vegetation control
Simazine	WP	49-392	Total vegetation control
Dinoseb	S	16-187	Broadleaf weed control
Pramitol	WP	19-114	Total vegetation control
Ureabor	G	4.5-67	Total vegetation control
Trifluralin	EC	13.7-54.8	Broadleaf weed control
Simazine	WP	9.81-39.2	Selective weed control
Diuron	WP	0.18-35.0	Selective weed control
Oxadiazon	WP	6.75-27.0	Selective broadleaf weed control
Pramitol	EC	3.81-22.9	Total vegetation control
Terbutryn	WP	5.47-17.1	Broadleaf weed control
2,4-D (ester)	EC	0.61-9.30	Broadleaf weed control
Dichlobenil	WP	1.5-7.9	Selective weed control
Picloram	EC	0.20-6.41	Broadleaf weed control
Chloflurenol	EC	0.33-5.90	Growth regulator
Oxadiazon	EC	1.35-5.40	Selective grass control
Diuron	S	0.024-4.80	Selective and total weed control
Fenac	S	0.56-4.10	Weed control and soil sterilant
Oryzalin	WP	1.36-3.57	Selective grass control
Bromacil	WP	0.30-3.0	Total vegetation control
2,4-D (salt)	S	0.19-3.0	Broadleaf weed control
Aminotriazole	WP	0.14-2.8	Total vegetation control
Glyphosate	S	0.49-0.97	Perennial weed control
MSMA	S	0.22-0.55	Selective grass control
Glyphosate	S	0.12-0.49	Annual weed control
Dicamba	EC	0.01-0.32	Brush and weed control
Aminotriazole	S	0.014-0.28	Total vegetation control
Cacodylic acid	S	0.082-0.25	Total vegetation control
Paraquat	S	0.25	Total vegetation control
DSMA	SP	0.092-0.18	Crabgrass and other weed control
Dicamba	S	0.005-0.16	Brush and weed control
Dalapon	SP	0.006-0.15	Perennial grass control
Ammate	SP	0.02-0.13	Brush and weed control
Diquat	S	0.056-0.12	Total vegetation control
Hexazinone	SP	0.034-0.067	Seasonal broadleaf control
Hexazinone	SP	0.010-0.028	Short term broadleaf control
Bromoxynil	EC	0.007-0.014	Broadleaf weed control

[a] The lower the value, the less the potential danger to aquatic environments from herbicide toxicity.

[b] Formulation: WP - wettable powder; S - Solution; EC - emulsifiable concentrate; SP - soluble powder; G - granules.

APPENDIX B

METHOD FOR SELECTING "ENVIRONMENTALLY PREFERABLE" INSECTICIDES FOR PEST CONTROL ON HIGHWAY RIGHTS-OF-WAY

The method for estimating the "relative impact" of insecticides is the same as that outlined in Appendix A for herbicides. Seasonal loss rates are multiplied by recommended application rates to obtain the average seasonal losses of insecticides to surface waters. This value, after being converted to mg/m^2, is divided by the lowest reported 96-hour LC_{50} to yield a "relative impact" value which is indicative of the potential for the insecticide to impact water quality (see Table 8). Actual seasonal loss rates, averaged from field measurements, were available for only two of the insecticide formulations listed in Table 9. Seasonal loss rates for the remaining insecticides were estimated based on formulations alone.

As with the herbicide method (Appendix A), the estimated seasonal loss values based on formulation alone may overestimate actual field losses since there are insufficient data available to assess persistence, leachability, and adsorptive properties of each insecticide. This overestimation is apparent when the actual seasonal loss rates for carbaryl and methoxychlor are compared to estimated loss rates based on formulations alone. For example, the estimated loss rate for an emulsifiable concentrate is 1 percent and the actual loss rate for methoxychlor in an emulsifiable concentrate formulation is 0.005 percent (Wauchope, 1978). However, although the final values may be overestimations, the purpose of this analysis is to compare insecticides to each other, not actually estimate losses. The use of consistent seasonal loss rates for each insecticide allows such a comparison to be made. Below is an example of the above selection method, followed by a worksheet for use by the highway agency.

<u>Example</u>

Objective = <u>mite control</u>

Insecticide now in use = <u>Dicofol</u>

Formulation = <u>wettable powder</u>

Ratio value = <u>63-850</u>

Alternative insecticide = Tetradifon

Formulation = wettable powder

Ratio value = 0.15 to 1.3

Work Sheet

Objective = ______________________

Insecticide now in use = ______________

Formulation = ______________________

Ratio value = ______________________

Alternative insecticide = ______________

Formulation = ______________________

Ratio value = ______________________

Table 8. Method for assessing the potential water quality impact of insecticides used for pest control on highway rights-of-way.

Insecticide	Use	Formulation[a]	Application rate[b] (lb/acre)	Seasonal loss rate (%)	Estimated[c] seasonal loss (lb/acre)	Lowest[d] reported 96-h LC_{50} (mg/l)	Relative impact Total loss / 96-h LC_{50}
Acephate	Contact/systemic insecticide	WP	0.5-1.0	5[e]	0.025-0.05	25.5	0.11-0.22
Carbaryl	Contact insecticide	WP	0.5-4.0	5[e]	0.025-0.20	0.69	4.1-32
		G	0.5-4.0	0.15[f]	0.00075-0.0060	0.69	0.12-0.97
Diazinon	Contact insecticide/ acaricide	WP	0.5-2.0	5[e]	0.025-0.10	0.02	140-560
		EC	0.5-2.0	1[e]	0.005-0.02	0.02	28-110
Dicofol	Acaricide for mite control	WP	0.6-8.0	5[e]	0.03-0.40	0.053	63-850
		EC	0.6-8.0	1[e]	0.006-0.08	0.053	13-170
Dimethoate	Insecticide/acaricide	WP	0.25-8.0	5[e]	0.013-0.40	7.5	0.19-6.0
		EC	0.25-8.0	1[e]	0.003-0.08	7.5	0.045-1.2
Malathion	Insecticide/acaricide	WP	0.50-3.0	5[e]	0.025-0.15	0.015	190-1100
		EC	0.50-3.0	1[e]	0.005-0.03	0.015	37-220
Methoxychlor	Insecticide	WP	0.25-0.50	5[e]	0.013-0.10	0.002	729-5600
		EC	0.25-0.50	0.005[f]	0.000013-0.00003	0.002	0.73-1.7
Tetradifon	Acaricide for mite control	WP	0.12-1.0	5[e]	0.006-0.05	0.88	0.76-6.4
		EC	0.12-1.0	1[e]	0.0012-0.01	0.88	0.15-1.3

[a] Formulations: WP - wettable; EC - emulsifiable concentrates; G - granules.

[b] Application rate represents extreme high and low dosages based on manufacturer information.

[c] Metric conversion factor: (lbs/acre) x (112.1) = (mg/m^2).

[d] 96-h LC_{50} values for fish species only.

[e] These loss rates are averages based on formulation alone.

[f] This loss rate is an actual field measurement for this insecticide.

Table 9. Insecticides rank ordered by the lowest relative impact value.[a]

Insecticide	Formulation	Ratio value[b]	Use
Methoxychlor	WP	729-5600	Insecticide
Malathion	WP	190-1100	Insecticide/acaricide
Dicofol	WP	63-850	Acaricide for mite control
Diazinon	WP	140-560	Insecticide/acaricide
Malathion	EC	37-220	Insecticide/acaricide
Dicofol	EC	13-170	Acaricide for mite control
Diazinon	EC	28-110	Insecticide/acaricide
Carbaryl	WP	4.1-32	Insecticide
Tetradifon	WP	0.76-6.4	Acaricide for mite control
Dimethoate	WP	0.19-6.0	Insecticide/acaricide
Methoxychlor[c]	EC	0.73-1.7	Insecticide
Tetradifon	EC	0.15-1.3	Acaricide for mite control
Dimethoate	EC	0.045-1.2	Insecticide/acaricide
Carbaryl[c]	G	0.12-0.97	Insecticide
Acephate	WP	0.11-0.22	Insecticide

[a] The lower the value, the less the potential danger to aquatic environments from insecticide toxicity.

[b] Formulations: WP - wettable powder; EC - emulsifiable concentrate; G - granules.

[c] Only insecticide formulations for which actual edge-of-field loss rates were available.

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