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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

Note: The Transportation Research Board, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

This primer concisely describes a new testing technology developed in NCHRP Project 25-09 to realistically measure how common highway construction and repair materials may affect surface and ground waters in environments surrounding highway rights-of-way. It uses nontechnical language to explain to executives and managers in state highway agencies, material supply firms, and the highway construction industry (as well as to the general public) how the test methods and supporting computer software can provide answers to questions about the environmental impact of new construction or the rehabilitation or repair of existing highways.

The effect on ecosystems and human health of constituents that migrate from the highway right-of-way through surface and ground waters is often uncertain. These constituents can originate from the in-service leaching of materials used in construction and repair of the roadway, or from construction procedures, vehicular operations, maintenance procedures, and atmospheric deposition.

Considerable research has been conducted on the water-quality impacts from highway and vehicle operations, maintenance practices, and atmospheric deposition, and on characterizing the chemical, physical, and biological contaminants in the roadway storm water runoff and their impacts on receiving waters.

While construction and repair materials have historically been held as innocuous and hence not of concern to environmental quality, there are legitimate questions about the impact of some of these materials on the environment. Furthermore, recycled and waste materials are increasingly being promoted as environmentally friendly substitutes for conventional construction and repair materials, thereby increasing the number of nontraditional materials in contact with surface and ground waters.

Under NCHRP Project 25-09, "Environmental Impact of Construction and Repair Materials on Surface and Ground Waters," a research team at Oregon State University was assigned the tasks of identifying potentially mobile constituents from highway construction and repair materials—whether conventional, recycled, or waste, but excluding constituents originating from construction processes, vehicle operation, maintenance operations, and atmospheric deposition—and measuring their potential impact on surface and ground waters. The research produced (1) laboratory methods to realistically simulate the leaching of constituents from construction and repair materials in typical highway environments; (2) laboratory methods to evaluate the removal, reduction, and retardation of leached constituents by environmental processes in the highway right-of-way; (3) extensive data sets of laboratory test results for highway construction and repair materials, expressed as both aquatic toxicity and as chemical concentrations; and (4) a software program, IMPACT, that estimates the fate and transport of such leachates in the environment surrounding the highway right-of-way. The IMPACT software contains an extensive, readily accessible database of laboratory test results for materials ranging from common construction and repair products to waste and recycled materials proposed for use in highway construction.

The contents of this primer are drawn from the results of NCHRP Project 25-09 presented in a comprehensive, five-volume final report prepared by the Oregon State University research team:

- Volume I: Environmental Impact of Construction and Repair Materials on Surface and Ground Waters;
- Volume II: Methodology, Laboratory Results, and Model Development for Phases I and II;
- Volume III: Methodology, Laboratory Results, and Model Development for Phase III;
- Volume IV: Laboratory Protocols; and
- Volume V: User's Guide, IMPACT.

Volume I is also planned for publication in the NCHRP Report series as Report 448, and all five volumes, the primer, and the IMPACT software will be distributed on a CRP CD-ROM.

CONTENTS

PRIMER
ENVIRONMENTAL IMPACT OF CONSTRUCTION AND REPAIR MATERIALS ON SURFACE AND GROUND WATERS

INTRODUCTION

There are more than 4 million miles of roadways in the United States, and 60 percent of those roads are paved (most with hot mix asphalt). This total includes bridges, culverts, and tunnels. In building and maintaining roads, highway agencies and contractors use a wide variety of manufactured materials. Increasingly, these materials include industrial by-products and recycled pavements and waste (such as tires), as well as additives to enhance the performance of the materials. A 1994 survey found that more than 24 waste materials or industry by-products have been used in at least 36 different highway applications.[1]

Over time, as rain falls and as melting snow runs off the pavement, components of these materials can leach out of the pavement or base and could be carried by the rainwater or snowmelt to nearby soil, ground, or surface waters. If these materials contain any potentially harmful constituents, the leachate could be harmful to the aquatic environment. (This study focused on leachates from pavements and other construction and repair materials. It did not address contaminants deposited on pavements from external sources, such as from vehicles and atmospheric fallout.)

NCHRP Project 25-9, *Environmental Impact of Construction and Repair Materials on Surface and Ground Waters*, sponsored a research team at Oregon State University to develop a methodology to screen common highway construction and repair materials for potential impact on the quality of surface and ground waters. The researchers also studied the movement (or transport) and eventual fate of the soluble components of highway materials. This report summarizes the results of that study.

Study Scope

The project's focus was on materials, preservatives, and additives present in the highway right of way. It did not include materials deposited on the pavement surface

[1] Collins, R. J. and Ciesielski, S. K., *NCHRP Synthesis of Highway Practice 199*, "Recycling and Use of Waste Materials and By-Products in Highway Construction." TRB, National Research Council, Washington, D.C., 1994, 84 p.

by vehicles or other means. The goal of the study was to develop an easy-to-use environmental screening methodology that would give highway agencies and industry a way to quickly evaluate specific construction and repair materials (whether new or recycled) that might harm the environment. The methodology includes chemical analysis as well as a series of aquatic bioassay tests to identify deleterious effects of construction and repair materials on ground and surface waters.

The study took a more "holistic" or real-world approach than traditional evaluations, which typically involve only chemical analyses. Chemical analysis alone cannot predict how a material will behave in an actual highway environment. Chemical analysis shows what is present and in what quantities, but reveals nothing about potentially harmful effects to the aquatic food chain. The methodology developed by the research team thus uses bioassays, which can assess the potential harm to the lower levels of the aquatic food chain, together with chemical analysis.[2]

Expected Audience and Intended Users

The new methodology will not only help highway agencies protect the environment, but will also help agencies explain to the public why they are using—or not using—a particular material (new or recycled) in a construction and repair project. The methodology is intended as a management and decision-making tool for state highway engineers and managers, public interest groups, environmental advocacy groups, and regulatory agencies involved in reviewing new materials for highway construction and rehabilitation.

How the Methodology Works

The procedures outlined in the methodology were tested on a wide variety of conventional and recycled highway construction and repair materials in a laboratory setting.

The methodology has been made as easy to follow as possible, but the user should be familiar with basic scientific concepts and practices. It is the first step toward the development of a recommended practice for highway agencies to use alone and in their interactions with contractors, suppliers, and regulatory agencies. The recommended practice is based on laboratory testing and validated methodology and includes a computer model and an associated database. The recommended practice would be used as a first-level screening tool when a highway agency is considering whether to approve a specific material for use in construction and repair projects. In addition, agencies could require consultants and material suppliers to use the recommended practice to screen materials for highway construction and repair projects. Highway agencies could then use the results of these screenings to coordinate approvals of questionable construction and repair materials on a regional or national basis.

Key Study Tasks

The most commonly used construction and repair materials (including recycled materials) were first screened to evaluate a broad spectrum of materials and to collect data that would be used to guide the succeeding phases. The study included development of a chemical and toxicological assessment for the most commonly used con-

[2] For more information, refer to the final reports from NCHRP Project 25-9: "Environmental Impact of Construction and Repair Materials on Surface and Ground Waters, Phases I–III" (Five volumes). TRB, National Research Council, Washington, DC, to be published.

struction and repair materials; a protocol for measuring and assessing aquatic toxicity; a concept for an analytical model to predict how—and to what extent—potentially harmful materials might migrate and infiltrate the soil; and a methodology for evaluating the toxicity of existing, as well as any new, construction and repair materials. Toxicity refers to the negative effects produced when an organism (in this case, the lowest level of the food chain) is exposed to a harmful material, or the property of a substance that causes those negative effects.

The emphasis of the project then shifted to developing an improved understanding of the leaching process, source terms, and degradation processes. The research team developed a model, which can be used both for screening and for evaluating materials, to predict what would happen to potentially harmful constituents in the highway environment. The researchers then verified the evaluation methodology and performed additional testing to validate the computer model.

The researchers compared the results with published data, including Material Safety Data Sheets, and found the published data to be of limited value in predicting the environmental effects of leachate from construction and repair materials.

Products

The project delivered several key products:

- Baseline data on conventional (new and recycled) construction and repair materials;
- Laboratory protocols for integrated bioassay and chemical analysis;
- A computer model for screening and evaluating materials in highway settings; and
- A recommended practice for screening and evaluating the impact of construction and repair materials on ground and surface waters.

MATERIALS TESTING

A key reason for conducting bioassay tests is their ability to detect the potential impacts of constituents that would, singularly or in combination, otherwise go undetected by chemical analysis.

Studies by the U.S. Environmental Protection Agency (EPA) indicate that laboratory tests can be used to reliably predict the behavior and effects of materials in the field. Four strategies can determine the potential effect of leachates from highway construction and repair materials, either alone or in combination:

- *Chemical analysis of soils and waters*. Because this strategy focuses chiefly on the EPA's list of priority pollutants, it can miss materials associated with a variety of other pollutants.
- *Comparison of measured chemical properties with available criteria or standards, such as EPA's Water Quality Criteria*. This is an indirect assessment of potential hazard, because no actual measurements are taken. It is limited to those chemicals for which criteria are available.
- *Field sampling of indigenous plants and animals to measure structural or functional changes*. Although this would be the most direct means of assessing environmental hazard, field sampling can be used only in certain circumstances because of the difficulty and expense of procuring indigenous plants and animals for testing.
- *Laboratory or on-site tests using standard test organisms*. This is a more direct means of measuring the toxicological hazard of specific construction and repair materials. Because toxicity tests can be conducted relatively quickly (48 to 96

hours for aquatic tests), the most severe toxicity cases can be readily identified, making it easier to set priorities for further evaluation.

The research team initially screened 100 of the most commonly used construction and repair materials used in a broad variety of applications. The results were then used to develop a list of representative materials to be screened for potentially harmful effects on the water flea, *Daphnia magna*, and the freshwater algae, *Selenastrum capricornutum* (see Table 1). A plant and an animal species were chosen for testing because biological differences between plants and animals cause them to react differently to chemicals.

A variety of materials were tested, including the following:

- Six types of asphalt cement (AC),
- Four types of portland cement (PC),
- Two types of air-entraining agents,
- Plasticizer,
- Four types of water reducers,
- Industrial by-products,
- Mine waste and slag,
- Scrap tires,
- Wood preservative,
- Dust palliatives,
- Aggregate, and
- Fly, bottom, and other ashes.

KEY FINDINGS

The potentially harmful effects of the tested materials were reported in terms of what percentage of a full-strength sample of leachate would pose harm to *Daphnia* and to freshwater algae. To prepare full-strength leachate samples for testing, material samples were mixed with deionized water for 24 hours, at a ratio of 1 g of material for every 4 ml of water. Deionized water was chosen to simulate rainwater. The solution was then filtered, and the leachate was tested in the laboratory.

Whole-effluent toxicity can be measured as lethal concentration or by how a material inhibits growth. For this project, two specific measures of toxicity were used: lethal concentration (LC_{50}) for *Daphnia* and growth inhibition (EC_{50}) for freshwater algae. [Water quality constituents are conventionally measured in concentration units (i.e., mg/l); however, toxicity is measured by LC_{50} or EC_{50} values.] The EC_{50} value is equivalent to the median effective concentration (as a percent of full-strength leachate) that affected the growth of 50 percent of the algae over a set time period. The LC_{50} value is equivalent to the median effective concentration that is lethal to 50 percent of *Daphnia* over a set time period. Lower EC_{50} and LC_{50} values indicate greater toxicity.

The study found the following relationships:

EC_{50} or LC_{50} value	*Potential for Harm*
<10 percent	Extremely high
10–20 percent	High
20–75 percent	Moderate
>75 percent	Low

The laboratory tests determined how leachate from construction and repair materials could potentially affect the environment. The test results were used to determine

TABLE 1 Results of materials tests

Category	Material	Source	Growth Inhibition of Algae?
Aggregates	Base Aggregates	Willamette River gravel (crushed)	No
	Phosphogypsum modifed base aggregates	Base aggregates with added phosphogypsum	Yes
	Fly ash modified base aggregates	Base aggregates with added fly ash	No
Ash	Fly ash, coal combustion, Ohio	Ohio power-generating facility	Yes
	Bottom ash, coal combustion, Ohio	Ohio power-generating facility	Yes
	Fly ash, coal combustion, Indiana	Indiana power-generating facility	No
	MSW bottom ash, Massachusetts	Massachusetts municipal solid waste incinerator	Yes
Asphalt	Fresh plant mix asphalt, California	California DOT (Caltrans)	Yes
	Crumb rubber–modifed asphalt mix	Mississippi DOT	Yes
	Nonmodified control asphalt mix	Mississippi DOT	No
	5% shingles mixed with 25% recycled asphalt pavement (shingles with asphalt)	Minnesota DOT	Yes

(*continued on next page*)

TABLE 1 (continued)

Category	Material	Source	Growth Inhibition of Algae?
Asphalt	30% recycled asphalt pavement (shingles control)	Minnesota DOT	Yes
	Bottom ash–modified asphalt mix	Oregon State University (OSU) lab preparation	No
	Foundry sand–modified asphalt mix	OSU lab preparation	Yes
	Steel slag (EAF)–modified asphalt mix	OSU lab preparation	No
	Steel slag (BOF)–modified asphalt mix	OSU lab preparation	No
	MSW bottom ash–modified asphalt mix	OSU lab preparation	Yes
	Nonmodified control asphalt mix	OSU lab preparation	No
	Recycled asphalt pavement, California	Caltrans	No
	Fresh plant mix, Minnesota	Minnesota DOT	No
Bricks	Aluminum oven bricks	Oregon DOT	No
Concrete	Concrete with plasticizer	OSU lab preparation	Yes
	Crushed concrete (-4 inches)	Minnesota DOT	No
	Methacrylate sealer	Polymer supplier, New Jersey	Yes
Mine wastes	Mine tailings	Montana	No

(*continued on next page*)

TABLE 1 (continued)

Category	Material	Source	Growth Inhibition of Algae?
Mine wastes	Soil sample	Idaho	No
Shingles scrap	Shingles	Minnesota DOT	Yes
Sand	Foundry sand	Wisconsin foundry	Yes
Scrap tires	Crumb rubber	Mississippi DOT	Yes
Slag	Steel slag, electric arc furnace	Ministry of Transportation, Ontario	Yes
	Steel slag, basic oxygen furnace	Ministry of Transportation, Ontario	Yes
	Blast furnace slag	Indiana	No
Sulfate wastes	Phosphogypsum	Florida Institute of Phosphate Research	Yes
Wood shavings	Ammononiacal Copper Zinc Arsenate	Wood preserving firm, Oregon	Yes

"worst case" effects, as well as to evaluate the effect of removal, reduction, and retardation (RRR) processes for mitigating the harmful effects.

Potentially harmful chemicals can be partially removed by RRR processes, which include volatilization, photolysis, and biodegradation. Because these processes take several days and most highway runoff sits on the surface for only minutes, it is not likely that these processes could significantly reduce any concentration of chemicals.

Most materials were tested in their pure form (i.e., as received from the supplier, which is not necessarily in the form they would eventually be used or present in the highway environment). Other materials also underwent more detailed testing, including testing of the material in the form in which it would be used in highway construction [for example, asphalt cement was first tested alone, and then later tested in a mixture with aggregate (asphalt concrete)]. The results are shown in Table 1.

Constituents can leach from some construction and repair materials, but in most cases, the leachate is harmless. Contamination is restricted because of the leaching rate, dilution, the slow movement through pavements and soils, and by sorption to soils. The materials conventionally used in pavements have been found to pose no harm to the environment, but if recycled materials (such as crumb rubber or roofing shingles) are added to the pavement mix, the risk can increase. Some sealers and preservatives in their pure form are harmful to algae, and the risk increases when these materials are mixed with other materials. (Some materials, such as the wood preservative ammoniacal copper zinc arsenate, are *designed* to be toxic to organisms.)

To determine how the adsorptive capacity of soils would affect the toxicity of construction and repair materials in highway runoff, three common U.S. soils—a poorly draining clayey silt soil (Woodburn), a well-drained silty soil (Olyic), and a well-drained sandy soil (Sagehill)—were tested with leachates considered potentially lethal to *Daphnia* and freshwater algae. As the leachate traveled through the soil, sorption took place reducing the risk to the aquatic environment.

In their pure form, some highway construction and repair materials could be harmful to aquatic organisms. In most cases, however, the risks to the environment markedly decrease or disappear once the material is mixed with other components (e.g., once an asphalt binder is mixed with aggregate). (See Table 2.) For all conventional materials, as well as for most of the recycled materials tested, leachate from highway materials has little or no impact on the aquatic environment.

EVALUATION PROCEDURE

If a highway agency wants to evaluate the potential toxicity of construction and repair materials, it should first conduct a thorough search of the database (knowledge base) to determine if the material has already been tested for toxicity. The database, which initially consisted solely of the results of this study, will expand as more data become available. If this search yields sufficient data on a particular construction and repair material, there is no need for additional laboratory testing, thus avoiding unnecessary expenditures of time and money. If insufficient data are available, however, the user will need to enlist the aid of a specialized laboratory, such as at a university, to conduct a series of screening tests. Figure 1 shows the evaluation methodology.

If the screening tests show no harm to the environment, no further testing is required. If, however, the screening tests indicate the potential for harm to the environment, additional tests must be conducted to evaluate the initial strength of the compound material in the condition expected in the highway environment and to determine how the material could affect the aquatic environment. Two types of tests are conducted—leaching tests and RRR tests. For fill materials, the leaching tests include column leaching and

TABLE 2 Comparison of potentially harmful effects of materials in pure form versus materials in final form (i.e., combined with other materials)

Material	Pure Form (EC_{50})	Final Form	Final Form (EC_{50})	Olyic Soil (EC_{50})	Sagehill Soil (EC_{50})	Woodburn Soil (EC_{50})
Foundry Sand	2%	Asphalt Concrete	46%	None	None	None
Crumb Rubber	4%	Asphalt Concrete	58%	None	None	None
Roofing Shingles	5%	Asphalt Concrete	64%	None	None	None
Plasticizer (0.025% mixture)	54%	Portland Cement Concrete	14%	Not determined	21%	37%

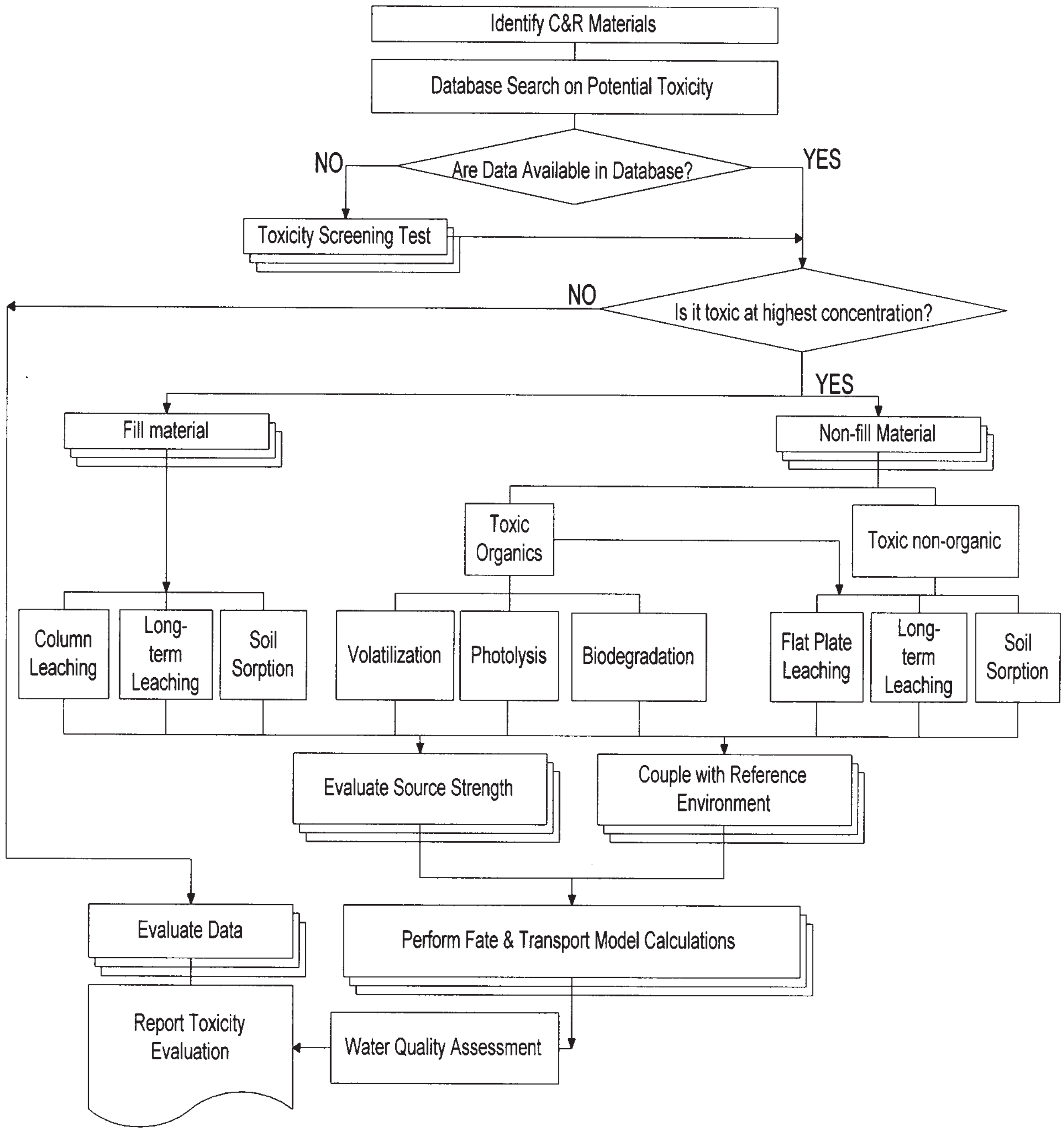

Figure 1. Steps in evaluating a construction and repair material.

long-term batch leaching. For nonfill materials, the tests include flat-plate leaching and long-term leaching. (See the appendix for more information on leaching tests.)

The RRR tests for both fill and nonfill materials consist of soil sorption tests. Volatilization, photolysis, and biodegradation tests are also conducted on nonfill materials that show evidence of organic materials in their leachate. The test results are then entered into a computer model, which computes the concentrations and loads of toxicants in runoff at the highway site boundary. If the tests indicate the materials could potentially harm the environment, the agency could switch to other materials or take steps to mitigate any harmful effects.

Because roadways are built of different materials and involve varying features, such as pavements and culverts, a series of tests is used to simulate the physical and chemical release of materials for a range of field conditions, as shown in Table 3.

TABLE 3 Laboratory tests used for various types of highway projects

Laboratory Test	Environment					
	Permeable highway surface	Impermeable highway surface	Piling	Fill	Bore Hole	Culvert
24-hour batch leaching	✓	✓	✓	✓	✓	✓
Long-term leaching	✓	✓	✓	✓	✓	✓
Column leaching				✓		
Flat-plate leaching	✓	✓	✓		✓	✓
Soil sorption	✓	✓	✓	✓	✓	✓
Degradation by photolysis	✓	✓				✓
Biodegradation	✓		✓	✓	✓	✓
Loss by volatilization	✓	✓				✓

Predictive Model

A numerical fate and transport model, in the form of a spreadsheet, is a key part of the evaluation methodology. The results from toxicity and chemistry tests have been entered into the database that is included with the model and which simulates the movement and transformation of constituents leached from construction and repair materials in six different field conditions (reference environments; see Figure 2). The model predicts what happens to the aquatic toxicity and composition of the constituents as they migrate to soil and possibly to ground and surface waters near the highway.

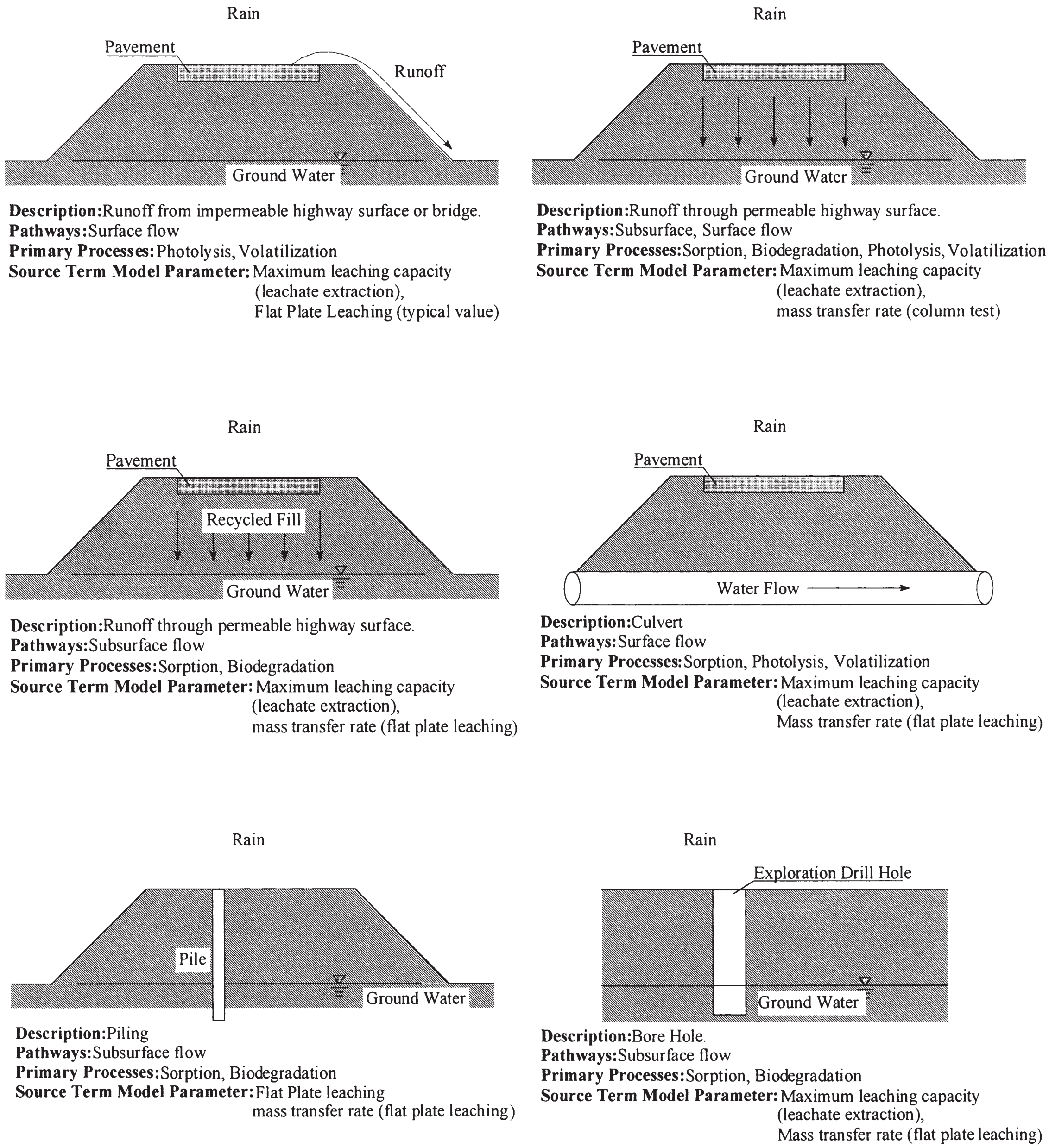

Figure 2. Model reference environments.

The model includes all principal known sources of leaching and RRR effects. The model predicts loads and concentrations in successive soil layers. The analyst can then interpret the output, based on comparison of concentration and toxicity with standards or benchmark values as well as estimates of dilution of loads from the highway to adjacent ground or surface waters.

Leaching rates in the model vary, depending on the type of construction and repair project being modeled: flat plate results are most appropriate for highway surface, piling, bore hole, and culvert projects; and column leaching is most appropriate for the fill projects.

The most important RRR process is sorption. For most materials, any potentially significant level of toxicity is reduced beyond detectable limits as the highway runoff percolates through the soil.

NEXT STEPS

The methodology is a ready-to-use tool for highway agencies striving to balance roadway performance with environmental health. Using this methodology, highway agencies can address some of the issues associated with Phase II National Pollutant Discharge Elimination System (NPDES) and bioassessment/biocriteria published by the U.S. EPA, the growing number of endangered and protected aquatic species, the establishment of aquatic habitats, wetlands protection, sediment quality, watershed management, and other environmental protection initiatives.

The database is a dynamic repository of data. To remain useful, it should be updated periodically with the results of agency-conducted testing.

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GLOSSARY

Acute Toxicity: A relatively short-term lethal or other detrimental effect, usually defined as occurring within 96 hours.

Aquatic Toxicity: A lethal or other detrimental effect produced by a substance in an aquatic species.

Assessment Endpoint: An explicit expression of an environmental endpoint that is to be protected as defined by an ecological entity and its attributes. For example, coho salmon are a valued ecological entity. Reproduction and age class structure are important attributes of coho salmon. Coho salmon reproductive success and age class structure form an assessment endpoint.

Batch Leaching: A leaching test in which no additional water is added during the test and the aqueous volume is kept constant. In the methodology, the usual procedure is to grind 1,000 g of the tested material, place the ground material in a vessel with 4 l of deionized water, and tumble the vessel to prepare the leachate.

Bioassay: A standardized procedure for determining the effects of an environmental variable or a substance on a living organism.

Breakthrough: The point at which a chemical constituent previously retarded by sorption in soil becomes available for transport to surface or ground waters.

Carcinogenicity: The potential for a chemical to act as a cancer-causing agent.

Chronic Toxicity: A relatively long-term lethal or detrimental effect often defined as occurring over the course of an exposure of one tenth or more of an organism's lifespan. Chronic should be considered a relative term depending on the lifespan of an organism. Chronic effects may include lethality, reduced growth, and reduced reproduction.

Construction and Repair Material: For this series of studies, substances that are used to build and maintain highway sections and structures. Substances such as deicers, materials deposited from vehicles, rainwater, or dry aerial deposition are not included.

***Daphnia magna*:** A species of tiny freshwater crustaceans, also known as water fleas, which are commonly used in aquatic toxicity bioassays.

Diffusion: The process of transporting a quantity (e.g., mass) of material in the direction of decreasing concentration.

EC_{50}: See Median Effective Concentration.

Eluent: The solvent used to extract potential contaminants from solid samples (i.e., the solvent used to produce leachates). The eluent used for this protocol is deionized or distilled water.

Fate: The ultimate disposition of a substance in the environment.

Flux: Rate of mass transfer, usually with mass per unit of area per unit of time.

Genotoxicity: Potential for a chemical to act as a DNA damaging agent.

Hazard: The potential for danger, harm, or negative irreversible effects to occur to an organism.

Hazardous Substance: A material that can pose a hazard to organisms, if the organisms are exposed through a suitable route to a sufficient concentration of the substance. A hazardous substance does not pose a risk unless an exposure potential exists.

LC_{50}: Median Lethal Concentration. See Median Effective Concentration.

Leachate: An elutriate used in further testing.

Long-Term Leaching: A leaching procedure that lasts more than 24 hours. The test continues until the concentrations of the chemical constituents in the leachate have reached a plateau. This is one of the procedures used in estimating the source terms of construction and repair materials.

Macroinvertebrate: An aquatic invertebrate species in which normal adults are retained by a 0.425-mm mesh screen. This is not a taxonomic or ecological classification. Rather, it reflects the importance of invertebrates in this size classification in aquatic food webs.

Mass Flux: The amount of mass passing through an area in a given amount of time.

Measure of Effect (Measurement Endpoint): A change in an attribute of an assessment endpoint, or its surrogate, in response to a stressor to which it is exposed (e.g., a change in lethality for *Daphnia magna* when exposed to a substance in a bioassay).

Median Effective Concentration, Median Lethal Concentration (EC_{50}, LC_{50}): A statistically or graphically estimated concentration of a substance in a bioassay that affects 50 percent of the tested population. When the endpoint is lethality, the term used is median lethal concentration (LC_{50}). Concentration is in terms of percent of full-strength leachate. Thus, lower EC_{50} and LC_{50} values indicate greater toxicity.

Modeling: The representation, often mathematical, of a process, concept, or operation of a system, often implemented as a computer program.

Mutagenicity: The potential for a chemical to increase the frequency of mutations by directly or indirectly modifying the genome or its expression.

Nontoxic: No Toxic Effect (NTE). No mortality of *Daphnia magna* at full strength of batch leachate, nor growth inhibition of *Selenastrum capricornutum* at 80 percent strength of batch leachate.

Photolysis: The chemical decomposition of materials under the influence of UV light.

Pollutant: A harmful substance or hazardous substance or product.

Pollution: The introduction of harmful substances or hazardous substances or products into the environment.

Reference Environment: A particular combination of highway runoff and contamination possibilities used to help model exports from the highway environment. This project uses six reference environments to represent the range of possibilities of pollution from highway construction and repair materials: (a) permeable pavement, (b) impermeable pavement surfaces, (c) culvert, (d) piling, (e) a filled bore hole, and (f) recycled fill.

Removal, Reduction, and Retardation (RRR) Processes: General term for those factors that will remove, reduce, or retard the impacts of a pollutant in the environment. Such processes include, but are not limited to, biodegradation, photolysis, and adsorption.

Selenastrum capricornutum: A species of green algae that is commonly used in aquatic toxicity bioassays.

Source Term: Quantity of a substance that is introduced into an ecosystem over a given period of time from a given area of construction and repair materials.

Toxicant: A substance capable of adverse effects on organisms when introduced into the environment.

Toxicity: The negative effects produced when an organism is exposed to a toxicant; the property of a substance that causes negative effects in organisms. In this report, toxicity is usually reported as a percentage (or fraction of) the concentration of the tested leachate.

Toxicity Assessment: The scientific art and process of estimating the toxicity impacts on assessment endpoints.

Toxicity Classification: The toxicity classification used in this report is as follows:

EC_{50} or LC_{50}	*Impact Category*
<10%	Extremely high
10%–20%	High
20%–75%	Moderate
>75% or inhibition	Low
No toxic effect	No impact

Toxicity Test: The means by which the toxicity of a substance is determined. Bioassays are a type of toxicity test.

Toxicity Unit (TU): The reciprocal of the fraction of the concentration that caused a toxic effect, often expressed as $1/(LC_{50})$, or $1/(EC_{50})$.

Transport: The processes by which a substance is carried, moved, conveyed, advected, diffused, or dispersed from one place to another.

Volatilization: The process of a substance migrating from a liquid into the atmosphere in the form of a vapor.

APPENDIX

LEACHING TESTS

Batch leaching tests are designed to determine rates of desorption and equilibrium sorption relationships under conditions of high mixing, high surface areas of the construction material, and continuous surface renewal.

Column leaching tests are designed to determine the rates of desorption under conditions of low mixing, high surface areas, and continuous surface renewal.

Flat-plate tests are designed to determine desorption under conditions of low mixing, low surface areas, and diffusion-limited surfaces.

An equilibrium test is a batch leaching test used under controlled pH conditions. Batch leaching tests simulate equilibrium leaching behavior (i.e., the concentration of a chemical that will leach under a defined pH).

A nonequilibrium test is a column leaching test conducted under various flow rates and flat-plate surface leaching. Column tests provide cumulative release data that describe leaching rates (concentration versus time) under conditions of constant surface renewal.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation