Framework for Evaluating Use of Recycled Materials in the Highway Environment

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FOREWORD

Recycling asphaltic and Portland cement concrete pavements back into new road construction or reconstruction is already widely practiced across the nation. This recycling represents an important obligation of the Federal Highway Administration (FHWA) and its partners at the State level to manage its own by-product materials. However, FHWA also recognizes that other recycled materials may also be appropriately used in highway infrastructure.

A number of states are experiencing increased interest and activity in use of recycled materials, some of which have excellent engineering properties and have been used successfully in other jurisdictions or countries. Applications for the use of more novel recycled materials in highway construction are also increasing. FHWA encourages the appropriate and economical use of recycled materials where engineering performance is equal to or exceeds traditional materials and where the materials do not contribute to current or future environmental problems.

In a similar vein, as stewards of the Nation's highways, FHWA desires to maintain a quality infrastructure and good roads. Use of recycled materials in the highway environment must promote this concept. Pavements and appurtenances have typical design lives and performance specifications that ensure a level of performance accepted by the engineering community and the public. Substitution of alternative materials must provide the same economic, engineering, and environmental benefits as traditional materials.

This manual is intended to provide guidance to assist transportation agencies in the maintenance of high-quality roads that perform to high engineering standards over their design life without future problems, and to promote cooperative efforts with environmental agencies to ensure that present and future environmental problems do not arise when recycled materials are used in highway infrastructure.

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16. Abstract

This manual is intended as a reference document for highway and environmental engineers who are interested in the utilization of recycled materials in the highway environment. The document provides a recommended evaluation methodology for determining the suitability of using recycled materials in highway construction.

The methodology is presented in the form of a hierarchy, where more general evaluations or screenings occur in the initial steps of the evaluation, followed by more detailed laboratory and field testing, if needed, as the evaluation proceeds. Detailed tables describing recommended testing methods and criteria to be used in the evaluation are provided.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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INTRODUCTION

Although many by-product materials such as recycled concrete material, recycled asphalt pavement, blast furnace slag, and coal fly ash have historically been used in the highway environment, methods for evaluating the engineering and environmental suitability of such materials have not been formally developed. Some State agencies have adopted regulatory or procedural frameworks for examining the potential for using recycled materials (sometimes referred to as a beneficial use determination or a new product evaluation process), but the absence of definitive methods of evaluation and specific criteria for determining the suitability of using such materials have in most instances limited the utility of these procedures.

The result is that both an applicant, who desires to use a recycled material, and a decision maker, who must determine the suitability of the application, in many cases do not have a clear or consistent approach (an evaluation framework) that can be used to proceed with such an evaluation. This report presents an evaluation framework for evaluating the feasibility of using recycled materials in the highway environment.

FRAMEWORK STEPS

The evaluation framework recommended in this report is illustrated in a flowchart format presented in Figure ES-1. The location in the main report of each item in the flowchart is identified in the figure. There are five steps in the framework.

- Step 1 – Select Material and Application

The first step in the framework process is to select a material and an application (e.g., use blast furnace slag in embankment construction) and submit the application to the evaluator or decision maker. In most cases the evaluator or decision maker(s) will be the State transportation and/or environmental agencies.

- Step 2 – Define and Evaluate Issues

The second step is to collect all relevant information that can provide input into the decision-making process. This includes, for the material and its proposed application, all related historical data, engineering and material property data, environmental, health and safety data, implementation constraints, recycling issues, and economic issues.

The purpose of this step is to define all issues that may warrant more detailed examination and in particular those issues that may be problematic insofar as approval of the material for use may be

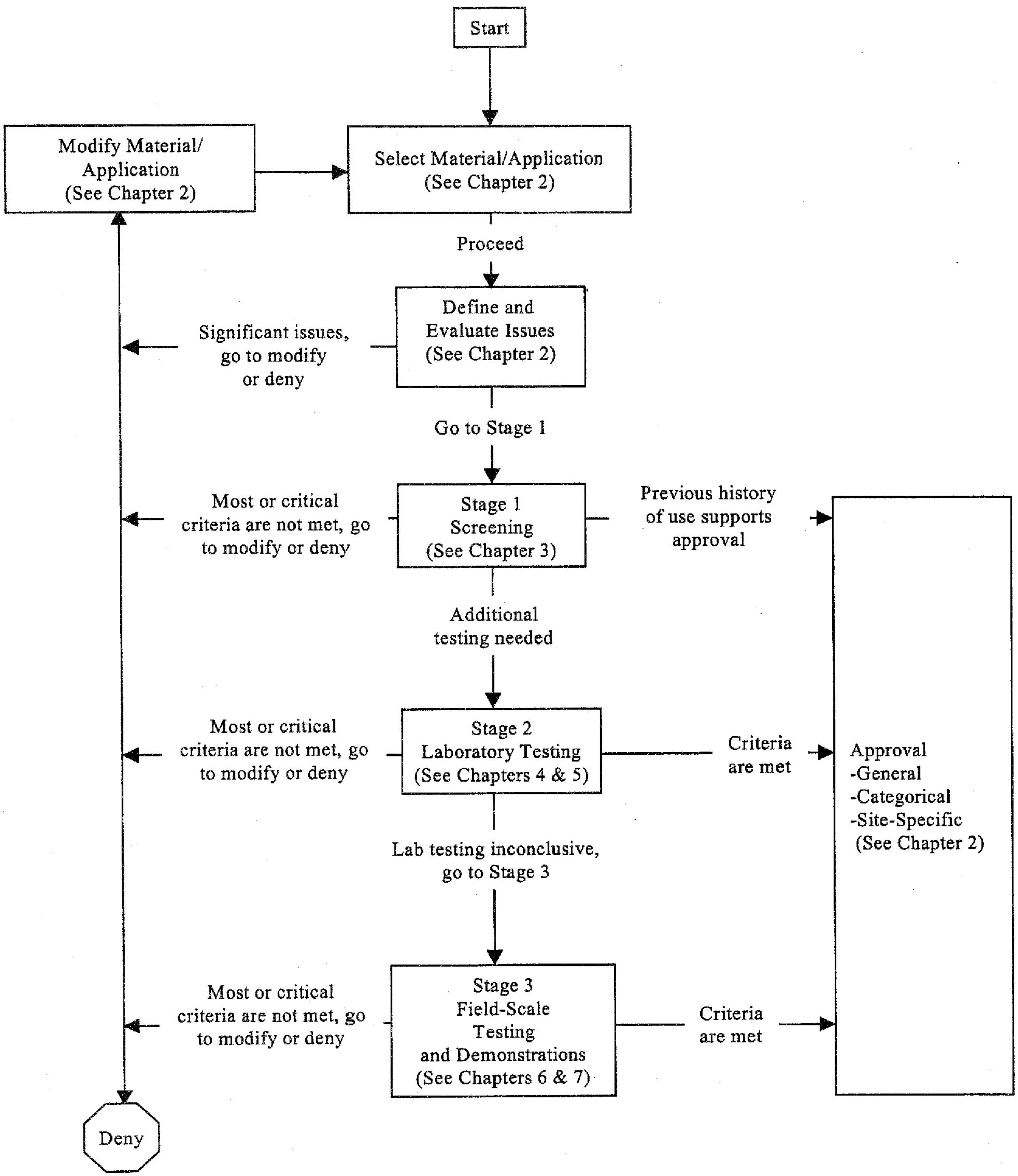

Figure ES-1. Evaluation framework flow process.

concerned. Recommended checklists to ensure that the proper information is collected for such an evaluation are provided in Chapter 2, Purpose and Methodology.

- Step 3 – Stage 1 Screening Evaluation

The third step in the process is a Stage 1 screen. The purpose of a Stage 1 screen is to determine whether the data collected in Step 2 are sufficient to approve (or reject) the proposed application without additional study. A Stage 1 approval means that the evaluator has a high degree of certainty that the applicant has provided sufficient information to justify acceptance of the proposed material and application. The applicant will typically be required to demonstrate that the proposed material is sufficiently similar to reference materials, which have been used successfully, to warrant approval.

A Stage 1 screen should include an assessment of all existing data pertaining to engineering data, environmental health and safety, data recycling issues, implementation concerns, political issues, and economic issues to ensure that the data are sufficient to permit a responsible decision. A series of recommended screening checklists, evaluation procedures, and evaluation criteria is presented in Chapter 3, Screening.

- Step 4 – Stage 2 Laboratory Evaluation

A Stage 2 laboratory evaluation is recommended if a Stage 1 review determines that existing information is insufficient to either accept or reject the application. The Stage 2 evaluation screen is intended to characterize (1) the engineering and materials properties and (2) the environmental, health, and safety properties of the proposed recycled material and its application product. These data can then be compared with established criteria or with the performance of reference materials using available laboratory and analytical engineering and environmental protocols.

To undertake a Stage 2 laboratory evaluation, it is recommended that (1) a test plan be prepared that delineates the samples to be tested and the tests to which the sample will be subjected, (2) acceptable specifications or performance criteria be identified that can be used as a means for evaluating the results of the test plan, and (3) the data be statistically evaluated to determine if specifications are met or if performance is similar to appropriate reference materials.

The most critical steps in a Stage 2 evaluation are development of the test plan and establishment of performance criteria. The main framework document provides a description of engineering and environmental parameters that will typically be of interest to decision makers when evaluating the use of proposed materials in specific applications and provides detailed lists of applicable laboratory test methods that can be used in the evaluation. Engineering and environmental parameters and test methods are presented in Chapter 4, Engineering Lab Tests and Chapter 5, Environmental Lab Tests, respectively.

- Step 5 – Stage 3 Field Scale Testing and Demonstration

A Stage 3 field testing may be warranted if the available data are still inconclusive after both Stage 1 and Stage 2 evaluations. Stage 3 is intended to provide field-scale data on (1) engineering and material properties, and (2) environmental, health, and safety properties of the proposed recycled material and its application product. These data can then be compared with established performance criteria or with reference materials (e.g., a control section).

Both engineering monitoring and environmental monitoring may be required during a field trial. Engineering monitoring refers to field evaluation activities that are intended to identify construction and performance aspects that may be affected by the use of a new material. Environmental monitoring refers to field evaluation activities that are intended to identify impacts to nearby air, soil, and water resources, as well as to the health and safety of workers that may result from the use or performance of the material.

Both short-term and long-term monitoring activities may be required for each type of monitoring activity. Short-term monitoring activities are activities designed to evaluate how the new material might affect the application during the end-product production process, such as asphalt or portland cement concrete production, and during and/or immediately after construction. Long-term monitoring activities are designed to evaluate how the proposed application performs during the post-construction period and can involve a time period ranging from several years up to the design life of the application.

To undertake a Stage 3 evaluation, it is recommended that (1) a demonstration test plan be prepared that delineates the field monitoring requirements, (2) acceptable specifications or performance criteria be identified to evaluate results of the field demonstration, and (3) the data be statistically evaluated to determine if specifications are met or if performance is similar to that of appropriate reference materials.

Field monitoring activities will differ, depending on the type of application being proposed. Recommended engineering and environmental field monitoring activities are presented in Chapters 6 and 7, respectively.

EVALUATION AND APPROVAL

The approval process, depicted in the lower right-hand box in Figure ES-1, is an integral part of the framework. Approval can occur at Stage 1, 2, or 3 of the evaluation process. Approval or rejection is dependent on the performance of the recycled material in the proposed application compared with potential criteria and specifications determined by the decision maker. Three types of approvals are possible: general, categorical, and site-specific.

General approvals are blanket approvals in which minimal, if any, conditions are imposed on the applicant. Such approvals are to be used where there is an overwhelming preponderance of data and history showing that the recycled material and application can be employed without adverse engineering or environmental consequences.

Categorical approvals impose more restrictive limits regarding where and how a material may be used. For example, such approvals may limit the use of a recycled material to a specific environment (e.g., a defined distance above the groundwater table), or to a specific location in the highway environment (e.g., base course as opposed to a wearing course pavement).

Site-specific approvals are one-time approvals and require the applicant to resubmit an application for the next project. These approvals normally require field monitoring to obtain additional information to assist the decision maker in assessing the suitability of the material in the proposed application.

FRAMEWORK FLEXIBILITY

The framework provides for combining or skipping steps if it is clear that such action is appropriate. For instance, if Step 2 determines that engineering or environmental data are insufficient, then the decision maker could decide to bypass a Stage 1 evaluation and undertake a Stage 2 and Stage 3 evaluation.

The framework also provides, as part of the stepwise evaluation process, the means to modify or beneficiate materials that do not meet criteria, so that the application will not be rejected out of hand without providing the applicant with an opportunity to revise the application on the basis of new data obtained during the evaluation process. This process is illustrated by the arrow directed toward the modify material application box in the upper left-hand corner of Figure ES-1.

FRAMEWORK LIMITATIONS

This document presents a comprehensive evaluation framework that decision makers can use when evaluating the use of recycled materials in highway applications. The complexity associated with defining evaluation procedures and criteria demands, however, that the evaluator select the best test methods and criteria subject to local conditions, and that the criteria and test methods be continually updated as new information is made available.

The multidisciplinary engineering and environmental effort involved in implementing the steps outlined in this framework will require that State engineering and environmental agencies forge cooperative efforts, pooling the necessary resources to undertake the necessary evaluation effort. Only through such cooperative efforts can these complex issues receive proper attention, ensuring the appropriate use of recycled materials in the highway environment.

OVERVIEW

There is an increasing interest on the part of the public, State regulators, the Federal Government, and industry to explore the use of recycled materials in the highway environment. Although many recycled materials have historically been used in the highway environment, use of recycled material is a relatively new concept in some States. There are also large differences between States about how recycled materials are evaluated and permitted for use.

The management and regulation of recycled materials use in the highway environment is jurisdictionally, at least in part, the responsibility of both the State transportation and environmental agencies. This document is meant to provide guidance to decision makers in each of these respective agencies in the evaluation and management of these materials.

Many by-product materials generated in the transportation sector, industrial sector, municipal sector, and mining sector of the U.S. economy have properties that make them potentially useful as recycled materials in the highway environment. Examples of materials generated in the transportation sector include reclaimed asphalt and portland cement concrete pavements, excess fill, street sweepings, and dredge materials. Examples of materials generated in the industrial sector include blast furnace slag, steel slag, nonferrous slags (e.g., copper, zinc, phosphate), sulfate wastes, coal combustion by-products (e.g., fly ash, bottom ash, boiler slag, flue gas desulfurization residues), kiln dusts (e.g., cement and lime-kiln), baghouse dusts (e.g., asphalt plant, smelters), foundry sands, and slags. Examples of materials generated in the municipal sector include waste glass, scrap tires, biosolids, construction and demolition (C&D) debris, wood waste, petroleum contaminated soils, roofing shingle scrap, plastics, wastewater sludge ash, and municipal solid waste combustor residues. Examples of materials generated in the mining sector include phosphogypsum, quarry waste, and mill tailings.

In the past, recycled materials have primarily been used in the transportation and industrial sectors. In the transportation sector, the use of excess asphaltic and concrete pavement for recycled asphalt pavement and reclaimed concrete material has become standard practice in most States. The use of materials generated in the industrial sector (primarily slags and coal combustion residues) has also been demonstrated, with good results.

Although the mining industry generates large quantities of by-product materials, the inaccessible location of most mining operations, relative to major metropolitan areas where the demand for highway construction materials is greatest, limits the potential for using large quantities of this resource in the near term.

Municipal wastes have potential uses, but inconsistent supply and small quantities associated with many individual waste streams (e.g., glass, shingles, plastics) relative to construction industry market requirements (which tend to require large quantities on demand) limit the attractiveness of these materials to most contractors.

Figure 1-1 illustrates some locations where recycled materials have the potential for use in a typical highway environment. These materials may be used to replace conventional materials in the fabrication or construction of highway appurtenances such as bridges, guardrails, and signs; as substitute materials for the pavement structure; as aggregates and supplementary cementitious materials in asphalt and portland cement concrete, granular or stabilized base and subbase; and as substitute embankment, fill, and landscaping materials.

Given the trend to recycle and utilize materials in the highway environment, materials introduced into a highway can be expected to be used more than once in one or more applications. Figure 1-2 is a diagram highlighting the life cycle of a recycled material used in the highway environment. At the completion of its initial service life, the new material may enter a secondary application (i.e., be recycled again) or be disposed of. Engineering and environmental issues need to be considered, not only when a recycled material is proposed for use during the initial service life of the material, but also in subsequent life cycles.

DEFINITIONS

For the purpose of this document, waste, recycled, reclaimed, and by-product materials are collectively grouped under the general category *recycled materials.* The use, reuse, or recycling of these materials into construction or reconstruction in the highway environment is collectively referred to as *recycled materials use* or *utilization.*

In addition, throughout this document, reference will be made to classes of materials as defined below:

Traditional Highway Materials – recycled materials originating in the highway sector that have historically been used with good results in highway construction applications (e.g., recycling of asphaltic pavements or portland cement concrete pavements back into new pavement construction or pavement reconstruction).

Traditional Recycled Materials in Traditional Application – recycled by-product materials originating in the industrial, municipal, or mining sector that have historically been used with good results in highway construction applications (e.g., the use of coal fly ash or blast furnace slag as a portland cement substitute in portland cement concrete pavements).

Traditional Recycled Materials in New Application – recycled by-product materials originating in the industrial, municipal, or mining sector that have historically been used for one application proposed for use in a new application (e.g., the use of reclaimed concrete aggregate in asphalt concrete pavements).

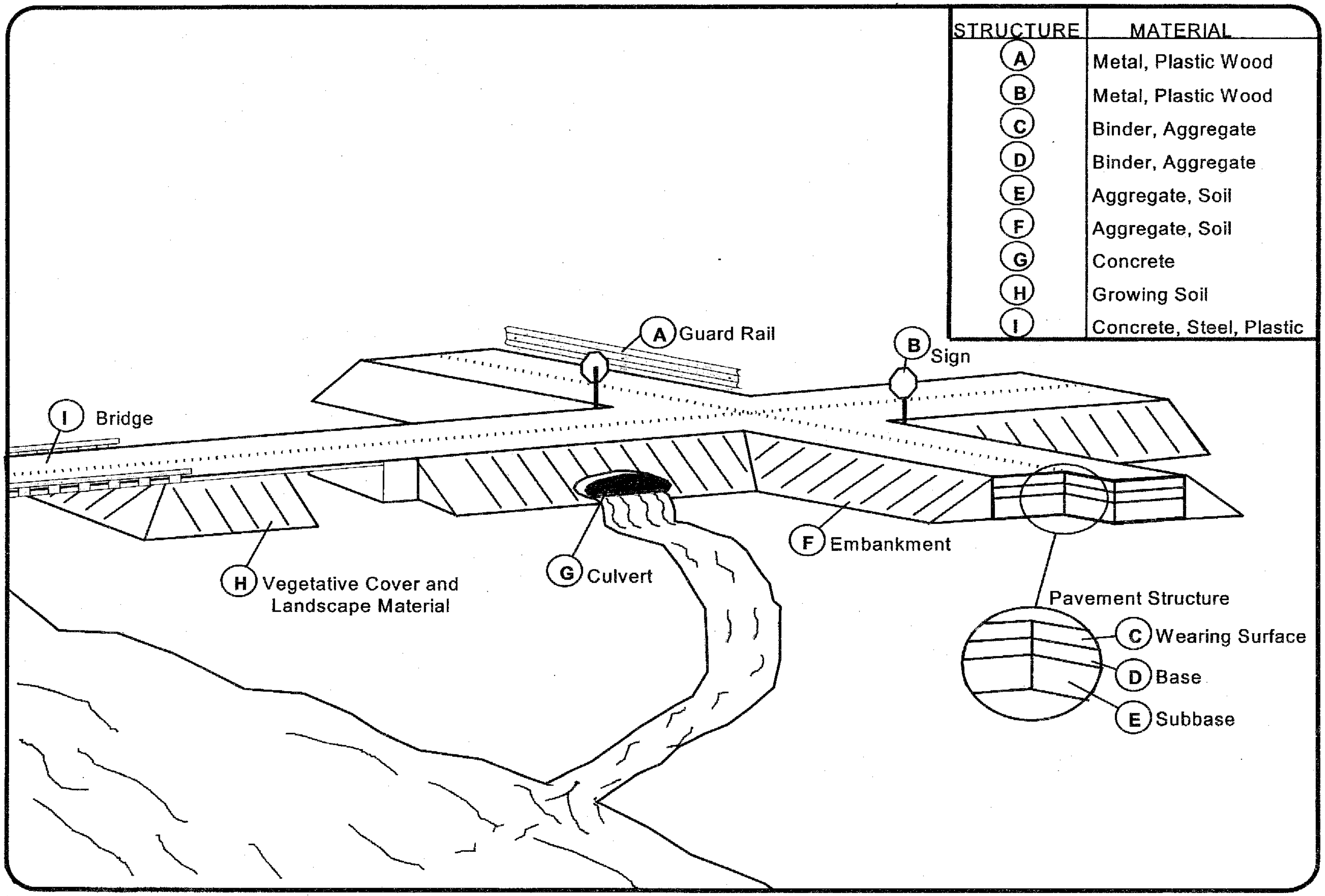

Figure 1-1. Schematic of the highway environment.

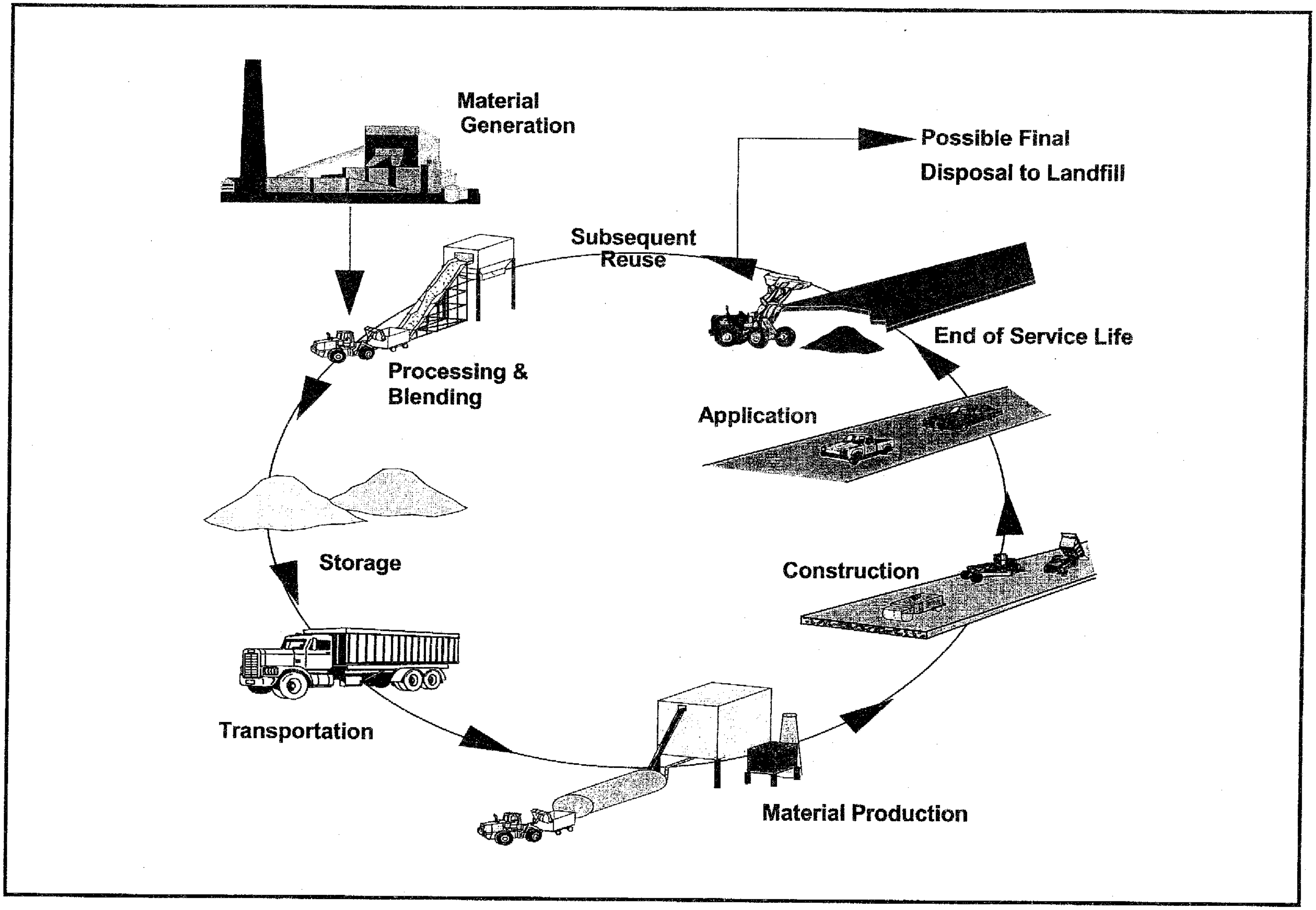

Figure 1-2. Life cycle of recycled materials.

New Recycled Materials in Traditional Application – recycled materials that have not been previously used (i.e., little or no historical data) in applications where other recycled materials have been used (e.g., the use of nonferrous slags as a portland cement substitute in portland cement concrete pavements).

New Recycled Materials in New Application – recycled materials that have not been previously used (i.e., little or no historical data) in new applications (e.g., the use of municipal solid waste bottom ash in cold emulsion stabilized base course).

Recycled Materials in Appurtenances – recycled materials (e.g., plastics) used in the manufacture of signs, barriers, or guardrails.

The term "traditional application" as used in the above definitions is meant to refer to highway construction applications in which the proposed material or similar types of recycled materials have previously been used. The term "new application" is meant to refer to a highway construction application in which the proposed materials or similar types of recycled materials have not been used.

SCOPE

In addition to this introduction, this document contains nine additional chapters. The chapter following this introduction provides a general description of the purpose of the framework and the general methodology used in the evaluation process. Subsequent chapters (3 through 7) provide detailed descriptions of the screening, laboratory testing, and field evaluation portions of the process. Chapter 8 provides an illustrative example of the process, Chapter 9 a statistical resource section, and Chapter 10 a web site resource section.

This guidance document will be maintained at the following web sites:

- http://www.rmrc.unh.edu
- http://www.tfhrc.gov

INTRODUCTION

The purpose of the evaluation framework is to articulate a logical process whereby a decision maker can evaluate a recycled materials utilization application and determine whether the proposed application is technically and environmentally feasible. Acceptance of a proposed application by State transportation and environmental officials means that all relevant engineering, environmental, health and safety, recycling, implementation, and economic issues have been properly addressed.

The framework presented is intended as a road map. It follows the process from conception through job-specific production with decision points to modify the recycled materials, if problems are encountered, or to deny the proposed application if problems cannot be rectified. The road map is intended to be a consensus-based document so that all parties in the decision-making process are aware of the evaluation procedure and the criteria that will be used to approve or reject the application.

FRAMEWORK FLOWCHART

The evaluation framework flowchart is presented in Figure 2-1. Figure 2-1 is a hierarchical flowchart, which flows from the general (i.e., less detailed) to the specific (i.e., more detailed) evaluation steps. It considers a selected recycled material (e.g., blast furnace slag) and a candidate application (e.g., asphalt concrete base course). Together, these constitute a material application or product (blast furnace slag as an aggregate substitute in asphalt concrete) that is to be considered.

Once the material and application are identified, it is the responsibility of all parties (particularly the decision makers) to define all relevant issues that need to be addressed in order to determine the feasibility of the application.

The process follows three hierarchical steps to evaluate the issues raised. In the Stage 1 screening step, all existing data are evaluated and it is determined whether the application can be approved without any additional testing. The Stage 1 screening step is presented in detail in Chapter 3. In the Stage 2 laboratory testing step, either engineering or environmental laboratory tests are conducted to obtain additional information on the suitability of the application. The Stage 2 engineering and environmental laboratory testing steps are presented in detail in Chapters 4 and 5, respectively. In the Stage 3 field testing step, the application is field tested to further validate its suitability. The Stage 3 engineering and environmental field testing steps are presented in detail in Chapters 6 and 7, respectively.

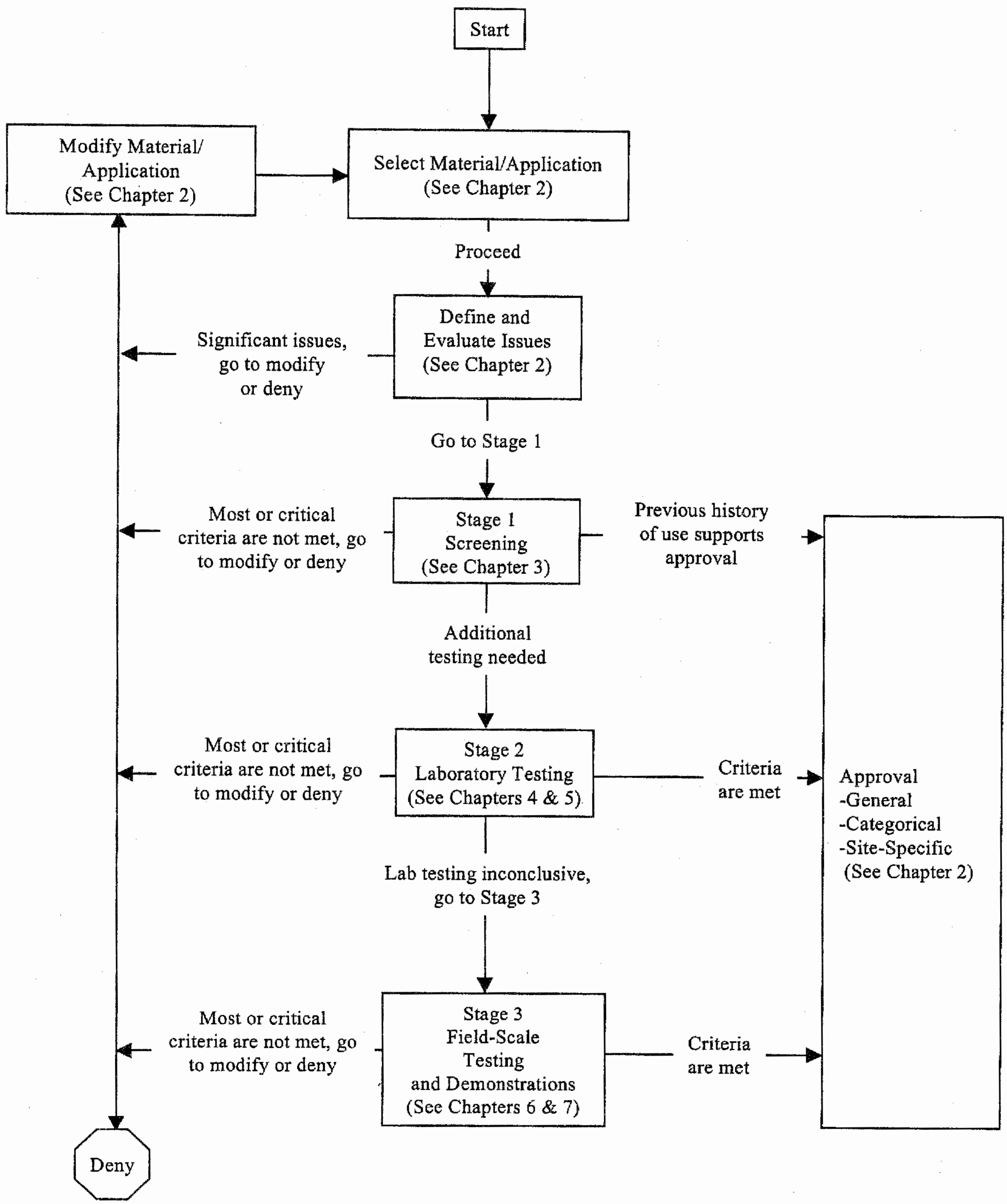

Figure 2-1. Evaluation framework flow process.

As an example of the process, one would expect that traditional highway or traditional recycled materials used in traditional applications with long track records of successful use, which are being proposed for use in an identical application in a different location (e.g., State) where the material had not yet been used, could be approved after a Stage 1 screen. One would also expect, however, that new recycled materials used in traditional applications, which are similar to traditional materials, would require some laboratory testing and evaluation (Stage 2) before the application would be approved. Additionally, one would expect that new recycled materials that are being proposed for use in a new application would require both Stage 2 laboratory testing and Stage 3 field testing before approval of the application would be considered.

The flowchart presented in Figure 2-1 provides for combining stages if it is clear from the original assessment that laboratory and field testing will be required. For instance, an initial assessment of the use of processed harbor sediments as an embankment material may suggest that laboratory testing and field placement are needed. This could mean that the applicant and decision maker would decide that combining a Stage 2 and Stage 3 evaluation is more appropriate than initiating sequential Stage 2 and Stage 3 evaluations.

The flowchart also provides, as part of the stepwise evaluation process, the means to modify or beneficiate materials that do not meet criteria so that the application will not be rejected out of hand without providing the applicant an opportunity to revise the application on the basis of new data obtained during the evaluation process.

This process contains some important limitations:

- This document is meant as guidance for States. It does not supercede existing State beneficial use determination (BUDs) or permitting programs, nor does it impose a Federal perspective on the States. Rather, it is meant to assist States in developing a comprehensive and consistent review and evaluation process for recycled material use.

- New or manufactured products or testing and evaluation criteria fall under existing State protocols with evaluation procedures or performance specifications dictated by the American Society for Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), or other testing protocols. This process is meant to work with or complement that process, not supercede it. As the reader examines this document, it will be readily apparent that different criteria may need to be developed, new evaluation tests may be needed, and evaluation of a specific project may perhaps depend on site-specific situations that cannot be addressed by this general document.

- Issues about the future environmental liability of recycled materials reused in the highway environment, particularly as they relate to Superfund designation, are presently being evaluated by U.S. EPA and are not expressly addressed here.

- The area of environmental assessment (as it relates to human and ecological risk) is an evolving one. Rather than prescribe a specific approach, a range of possible approaches is provided as these tend to encompass the approaches being adopted by State environmental regulatory agencies.
- It is assumed that State transportation and environmental agencies will both be involved in the evaluation process to address the multidisciplinary engineering and environmental issues that are presented in the framework.

SELECT MATERIAL/APPLICATION

Types of Applications

The first step in the framework process is the selection by the applicant of a material and application. There are seven major application categories in the highway environment in which recycled materials have their greatest potential applicability. These include asphalt concrete pavements, portland cement concrete pavements, granular base, embankment or fill, stabilized base, flowable fill, and landscaping applications. Other applications exist (e.g., curb and gutter, medians, guardrails, signs, etc.), but these applications utilize smaller quantities of materials than the aforementioned applications, and their evaluation methods (testing and criteria) are dictated by special industrial standards.

Asphalt Concrete

Asphalt concrete pavements consist of a combination of layers, which include an asphalt concrete surface constructed over a granular or asphalt concrete base and a subbase. The entire pavement structure, which is constructed over the subgrade, is designed to support the traffic load and distribute the load over the roadbed. Pavements can be constructed using hot mix or cold mix asphalt. Surface treatments are sometimes used during pavement construction. A surface treatment acts as a waterproof cover for the existing pavement surface and also provides resistance to abrasion by traffic.

Portland Cement Concrete

Portland cement concrete pavements (or rigid pavements) consist of a portland cement concrete slab that is usually supported by a granular or stabilized base and a subbase. In some cases, the portland cement concrete slab may be overlaid with a layer of asphalt concrete.

Granular Base

Aggregates are used in granular base and subbase layers below the driving surface layer(s) in both asphalt concrete and portland cement concrete pavement structures. The aggregate base layers serve a variety of purposes, including reducing the stress applied to the subgrade layer and providing drainage for the pavement structure. The granular base layer is directly below the pavement surface and acts as the load-bearing and strengthening component of the pavement structure. The granular subbase forms the lowest (bottom) layer of the pavement structure. It acts as the principal foundation for the subsequent road profile, provides drainage for the pavement structure, and protects the structure from frost.

Stabilized Base

A stabilized base is a class of paving materials that are mixtures of one or more sources of aggregate and either bituminous or calcium-based cementitious material(s) that can be compacted to form a dense mass. A stabilized layer can be used as an alternative means of supporting overlying pavements and/or to strengthen weaker base or subbase components in a pavement structure.

Embankment or Fill

An embankment refers to a volume of earthen material that is placed and compacted for the purpose of raising the grade of a roadway (or railway) above the level of the existing surrounding ground surface. A fill refers to a volume of earthen material that is placed and compacted for the purpose of filling in a hole or depression. Embankments or fills are constructed of materials that usually consist of soil, but may also include aggregate, rock, or crushed paving material.

Flowable Fill

Flowable fill refers to a cementitious slurry consisting of a mixture of fine aggregate or filler, water, and cementitious material(s), which is used primarily as a backfill in lieu of compacted earth. This mixture is capable of filling all voids in irregular excavations and hard to reach places (such as under and around pipes), is self-leveling, and hardens in a matter of a few hours without the need for compaction in layers. Flowable fill is sometimes referred to as controlled density fill (CDF), controlled low strength material (CLSM), lean concrete slurry, and unshrinkable fill.

Landscaping Materials

In the highway environment, there is a need for landscaping materials that can be used as soil amendment, top cover, mulch, grading material, and erosion control material. It is of added benefit if these materials have nutrient value, particularly when they will be supporting vegetative growth.

Examples of Applications of Recycled Materials

Table 2-1 lists recycled materials that have been used or have the potential for use, based on their engineering properties, in the seven major application categories previously described. As is evident in the table, many potentially recyclable materials have a number of potential uses. For instance, coal fly ash has been used as a mineral filler in asphalt paving, as mineral admixture in portland cement concrete, as fill material in embankments, as pozzolan in stabilized base, and as a fine aggregate in flowable fill mixes.

DEFINE AND EVALUATE ISSUES

Purpose of the Define and Evaluate Issues Step

The second step in the framework process is the issues definition step. The purpose of this step is to identify all relevant historical activities, engineering and materials property data, environmental health and safety data, potential implementation issues, future recycling issues, and economic issues associated with the proposed material application. During this step, an evaluation should be made to determine whether there are any readily apparent issues that could warrant rejection or modification of the proposed application.

The degree and detail to which this step is addressed can dictate whether the evaluation proceeds in a proper manner. If the effort in this step is incomplete, then key historical, material property, environmental, health and safety, implementation, recyclability, and economic data can be missed. This can result, at best, in the expenditure of unnecessary funds to duplicate previous efforts by reevaluating a material that is already in use or, at worst, the omission of key issues in the evaluation process that could result in either approval or disapproval of the proposal on the basis of incomplete data.

Description of Key Issues

A flowchart that can be used to identify the key issues in any material-application proposal is presented in Figure 2-2. The flowchart makes reference to Tables 2-2 through 2-7 that illustrate each respective step in the issues identification process. The six tables include Table 2-2, which addresses the issues associated with history and previous experience; Table 2-3, which addresses materials and engineering property issues; Table 2-4, which addresses environmental, health, and safety issues; Table 2-5, which addresses implementation issues; Table 2-6, which addresses recycling issues; and Table 2-7, which addresses economic issues.

Table 2-1. Potential uses of recycled materials in various applications.

Application	Recycled Material	
Asphalt Concrete Pavement		
Mineral Filler	Asphalt Plant Dust Sewage Sludge Ash Cement Kiln Dust	Lime Kiln Dust Coal Fly Ash
Asphalt Aggregate (Hot Mix)	Blast Furnace Slag Coal Bottom Ash Coal Boiler Slag Foundry Sand Mineral Processing Wastes Municipal Solid Waste Ash Nonferrous Slags	Petroleum Contaminated Soils Reclaimed Asphalt Pavement Roofing Shingle Scrap Scrap Tires Steel Slag Waste Glass
Seal Coat or Surface Treatment Aggregate	Blast Furnace Slag Coal Boiler Slag	Steel Slag
Asphalt Cement Modifier	Roofing Shingle Scrap Scrap Tires	Plastic
Portland Cement Concrete Pavement		
Mineral Admixture or Cement Additive	Coal Fly Ash	Blast Furnace Slag
Portland Cement Concrete Aggregate	Reclaimed Concrete	
Granular Base		
Granular Base Materials	Blast Furnace Slag Coal Bottom Ash Coal Boiler Slag Combustor Ash Foundry Slag Mineral Processing Wastes Municipal Solid Waste	Nonferrous Slags Petroleum Contaminated Soils Reclaimed Asphalt Pavement Reclaimed Concrete Steel Slag Waste Glass
Stabilized Base		
Stabilized Base or Subbase Aggregate	Coal Bottom Ash Coal Boiler Slag	Petroleum Contaminated Soils
Stabilized Base Supplementary Cementitious Material	Coal Fly Ash Cement Kiln Dust	Lime Kiln Dust Sulfate Wastes
Flowable Fill		
Flowable Fill Aggregate	Coal Fly Ash Foundry Sand	Quarry Fines
Supplementary Cementitious Material	Coal Fly Ash Cement Kiln Dust	Lime Kiln Dust
Embankment and Fill		
Embankment or Fill Materials	C&D Debris Coal Fly Ash Mineral Processing Wastes Nonferrous Slags	Petroleum Contaminated Soils Reclaimed Asphalt Pavement Reclaimed Concrete Scrap Tires
Landscaping Material		
Soil Amendment, Top Cover, Mulch	Biosolids Wastewater Sludge Compost	Wood Chips C&D Wood Waste

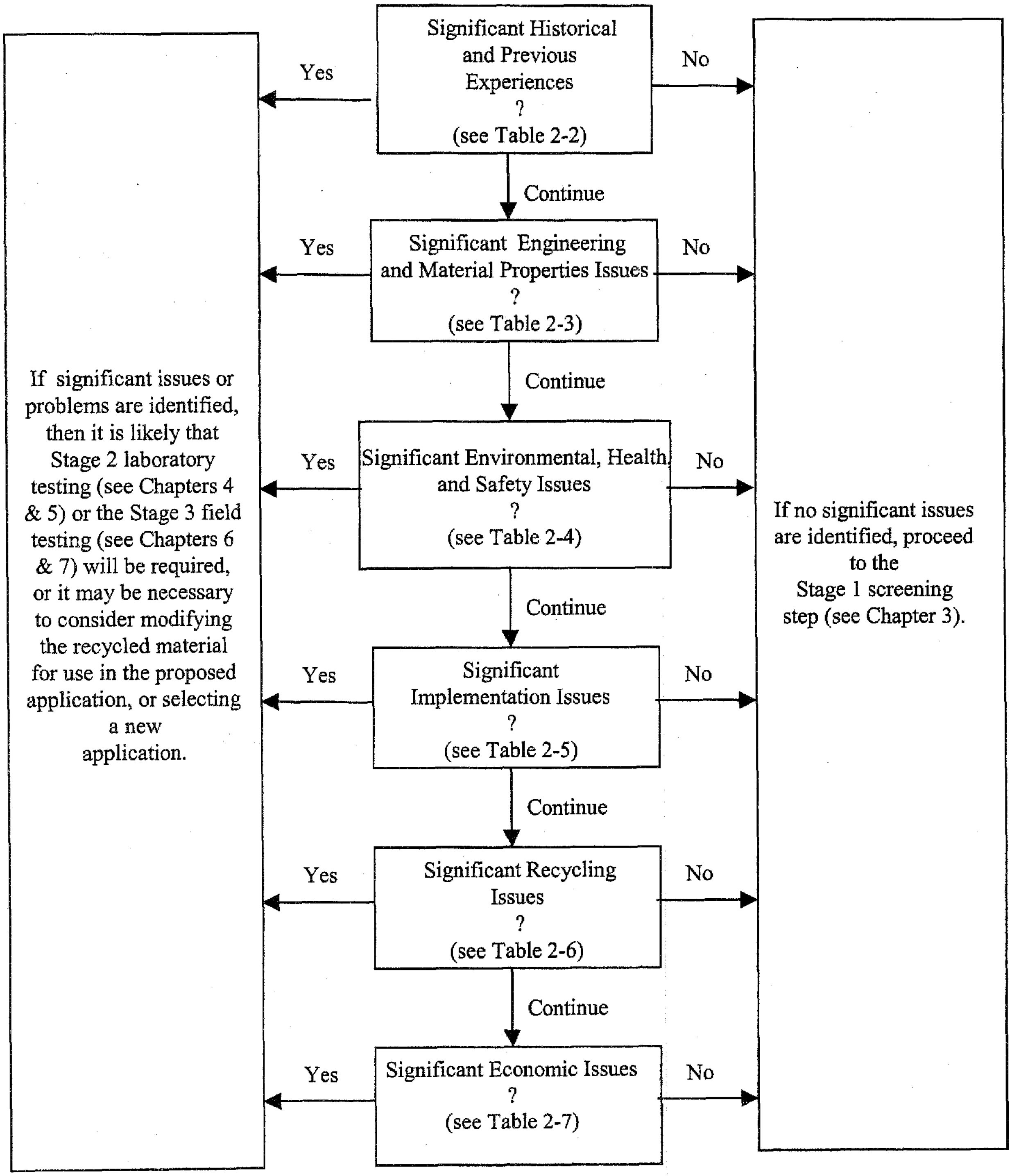

Figure 2-2. Issues evaluation steps.

Table 2-2. History and previous experience questions.

General Area	General Questions[1]	
History	1. Has the recycled material been used before? If so, identify uses.	Y ☐ N ☐
	2. Is information available about the source of the recycled material? If so, collect it.	Y ☐ N ☐
	3. Has this recycled material been previously used? If so, identify applications.	Y ☐ N ☐
	4. Has this recycled material been used in geographically diverse locations? If so, identify locations.	Y ☐ N ☐
	5. Has it been used previously in a similar application? If so, identify location.	Y ☐ N ☐
	6. Has this recycled material been used in other jurisdictions? If so, identify jurisdiction.	Y ☐ N ☐
	7. Have other jurisdictions granted use? If so, identify jurisdictional province.	Y ☐ N ☐
Previous Experience	1. Is information available about important prior experiences (previous use, prior objections, similarity with other materials)? If so, collect the information.	Y ☐ N ☐
	2. Are there experts available to discuss prior experiences? This can include regulators, scientists, practitioners, waste generators, associations. If so, contact the experts.	Y ☐ N ☐
	3. Is there any published literature about prior experiences? If so, obtain the information.	Y ☐ N ☐

1. Y = Yes, N = No

Table 2-3. Engineering and materials properties questions.

General Area	General Questions[1]	
Engineering	1. Is information available about the engineering properties of the recycled material? This could include information about gradation, bulk density, durability, and compaction data. If so, collect the pertinent information.	Y ☐ N ☐
	2. Is the recycled material appropriately characterized with respect to time-dependent engineering properties? This could include time-dependent variation in gradation, bulk density, durability, and compaction. If so, collect the pertinent information.	Y ☐ N ☐
	3. For the proposed application, are there appropriate engineering criteria for the product? This could include durability, grain size, and compaction requirements. If so, collect the pertinent criteria.	Y ☐ N ☐
	4. Is engineering information available about important prior experiences (previous use, prior performance criteria, similarity with other materials)? If so, assemble the pertinent information.	Y ☐ N ☐
Materials Properties	1. Is information available about the materials properties of the recycled material? This could include information about loss on ignition, mineralogy, and pozzolanic activity of the waste material. If so, summarize the data.	Y ☐ N ☐
	2. Is the recycled material appropriately characterized with respect to time-dependent materials properties? If so, summarize the data.	Y ☐ N ☐
	3. For the proposed application, are there appropriate materials properties criteria for the product? If so, identify the criteria.	Y ☐ N ☐

1. Y = Yes, N = No

Table 2-4. Environmental, health, and safety (EHS) properties questions.

General Area	General Questions[1]	
Environmental	1. Is information available about the environmental properties of the recycled material? This could include information about total elemental composition, total available element composition, and volatile and semi-volatile organics composition data. If so, collect the pertinent information.	Y ☐ N ☐
	2. Is the recycled material appropriately characterized with respect to time-dependent environmental properties? This could include time-dependent variation in total elemental composition, total available element composition, and volatile and semi-volatile organics composition. If so, collect the pertinent information.	Y ☐ N ☐
	3. For the proposed application, are there appropriate environmental criteria for the product? This could include leaching data, total content data, particle size, etc. If so, collect the pertinent criteria.	Y ☐ N ☐
	4. Is environmental information available about important prior experiences (previous use, prior performance criteria, similarity with other materials)? If so, assemble the pertinent information.	Y ☐ N ☐
	5. Have there been any environmental assessments undertaken relative to the use of the proposed material. If so, summarize the information.	Y ☐ N ☐
Public Health	1. Are there any Materials Safety Data sheets (MSDS) for the recycled materials? If so, collect the sheets.	Y ☐ N ☐
	2. Have there been health risk assessments (HRA) undertaken relative to the proposed use of the material? If so, summarize the information.	Y ☐ N ☐
Safety	1. Have there been prior OSHA issues for generation, processing, storage, and use in previous efforts? If so, summarize the information.	Y ☐ N ☐

1. Y = Yes, N = No

Table 2-5. Implementation issue questions.

General Area	General Questions[1]	
Implementation	1. Are there any apparent political constraints? If so, describe them.	Y☐ N☐ U☐
	2. Are there any apparent regulatory constraints? If so, describe them.	Y☐ N☐ U☐
	3. Are there any apparent public acceptability constraints? If so, describe them.	Y☐ N☐ U☐

1. Y = Yes, N = No, U = Unknown

Table 2-6. Recycling issue questions.

General Area	General Questions[1]	
Recycling	1. Are there likely recycling or life-cycle issues? If so, identify them.	Y☐ N☐ U☐
	2. Has the recycled material or its application been reused within other areas of the highway environment? If so, identify them.	Y☐ N☐ U☐

1. Y = Yes, N = No, U = Unknown

Table 2-7. Economic issue questions.

General Area	General Questions[1]	
Economic	1. Are there any apparent economic constraints? If so, identify them.	Y☐ N☐ U☐

1. Y = Yes, N = No, U = Unknown

STAGE 1 – SCREENING

The next step in the framework process is the Stage 1 screening step. The Stage 1 screening step includes screening procedures for engineering and materials properties, environmental, health and safety, recycling, implementation, and costs. The purpose of the Stage 1 screen is to determine, on the basis of existing data, whether the proposed application can be approved without additional study. Such approval, in the absence of any additional testing, means that the decision maker has a relatively high degree of certainty that the applicant has provided sufficient information to justify acceptance of the proposed material and application. This will necessitate that the applicant demonstrate that the proposed material is sufficiently similar to a "reference" material (a material that is produced, processed, and utilized in a similar manner) to warrant approval of the application.

This screening step is most applicable in situations where (1) traditional materials are being proposed for use in traditional applications, (2) the materials have been used historically without problem, (3) there are large data sets from other locations, and (4) the environment in which it is being proposed for use is similar to those environments in which is has been previously used. As an example, an application that proposes the use of waste glass as part of a granular base might be suitable for a Stage 1 screening approval, if the applicant can show that waste glass that has been processed in a similar matter has been successfully used in similar applications in another location.

This stage is not likely to result in approvals for use for traditional recycled materials in new applications, new recycled materials in traditional applications, or new recycled materials in new applications without additional (Stage 2 or Stage 3) study.

STAGE 2 – LABORATORY TESTING

The next step in the framework process is the Stage 2 laboratory testing evaluation. The Stage 2 testing evaluation is intended to characterize (1) the engineering and materials properties and (2) the environmental, health, and safety properties of the proposed recycled material and its application product. These characterization data can then be compared with established criteria or to the performance of reference materials using similar laboratory protocols.

This Stage 2 laboratory testing stage is applicable in situations where (1) there is insufficient historical information to adequately assess the properties of the proposed material, or (2) because of uncertainty with respect to the reliability of historical data, verification of these data is warranted.

A detailed presentation of Stage 2 testing engineering and environmental recommendations is presented in Chapters 4 and 5, respectively.

INTRODUCTION

A Stage 1 screening procedure can be designed to address engineering, environmental, health and safety, recycling, implementation, and economic issues. Recommended screening procedures for each of the above referenced issues are presented in this chapter.

ENGINEERING

To undertake a Stage 1 engineering screening procedure, it is recommended that (1) a comparative source assessment be undertaken, which includes an analysis of the production or generation processes of the proposed and reference materials to verify that they originate from the same type of source, (2) a comparative materials properties assessment be undertaken, which includes an evaluation to determine whether the properties of the proposed and reference materials are sufficiently similar, and (3) a historical field performance assessment be undertaken, which includes a determination from historical records that the material will perform satisfactorily in the proposed application.

Figure 3-1 provides a flowchart highlighting the three steps in a Stage 1 engineering screen. Included in Figure 3-1 is reference to Table 3-1, which provides additional guidance on evaluating the material source, engineering properties, and field performance history of the material during a Stage 1 screen.

Materials Source Assessment

The materials source screening test method, presented in Figure 3-1 and Table 3-1, requires that sufficient information be presented by the applicant to permit the decision maker to determine that the proposed material is or will be generated and processed in a manner similar to the historical reference material, and that changes in the production, generation, or post-production operations will not impact the quality of the proposed material with respect to the intended application.

If the quality of the feedstock material in any commercial or industrial operation is altered, one can expect some modification in the quality of the recycled material generated or produced in the process. For example, if the feedstock material for waste glass, which is being crushed and screened for use as a fine aggregate, is switched from a glass supplier that provides clean crushed glass (e.g., glass-only processor) to a supply of glass from a municipal recycling facility that processes curbside recyclables that consist of metal cans, plastic containers, and glass), the quality of the glass (with respect to the introduction of non-glass contaminants) can be expected to decrease.

Many commercial and industrial operations periodically alter their production processes. Such modifications could impact the material quality. For example, an increase or decrease in the

Engineering Property Data

The comparative engineering properties assessment, presented in Figure 3-1 and Table 3-1, requires that the applicant provide sufficient data to the decision maker to demonstrate that the proposed and reference materials exhibit comparable engineering properties and conform to established specifications. If proposed material data are unavailable (i.e., in a case where the recycled material has not yet been produced), the decision maker must be satisfied that both the proposed and reference materials will exhibit the same properties based solely on the presentation of information provided in the material source assessment.

It is important that the engineering properties assessment be undertaken in conjunction with the materials source assessment to ensure that not only the engineering property data will be comparable, but the expected variability in the data will be such that the desired statistical comparability of the data will be maintained during continuous operation.

The type of engineering property data that should be included in this assessment will depend on the specific application (e.g., granular base material or aggregate substitute in asphalt concrete) and the design approach used by the specifying jurisdiction. For example, the engineering properties of the recycled material itself will determine whether the material will perform in a granular base application, while the properties of both the material and the blended mix will determine whether the material will adequately perform as an aggregate substitute material in asphalt concrete. In addition, each specifying jurisdiction may require specific design and evaluation criteria. The current use of Superpave mix design methods by some jurisdictions could negate historical data in which alternative mix design procedures (e.g., Marshall or Hveem methods) were used. In any engineering property screen the decision maker will ultimately be responsible for defining the specific property data that will be required for approval.

As part of the evaluation process the decision maker should ensure that not only adequate engineering property data are available to make an affirmative decision regarding the proposed application, but that the source(s) of the data (e.g., agency or laboratory conducting the testing) is reliable, that the sample statistics of the engineering property data provided by the applicant for the proposed and reference materials are comparable, and that they are within the design criteria of the specifying jurisdiction. Illustrative examples of methods to statistically evaluate the engineering property data are presented in Chapter 9.

Historical Field Performance Assessment

The historical engineering and materials property field performance assessment, presented in Figure 3-1 and Table 3-1, requires that an evaluation be undertaken of the historical field performance of the reference material. An affirmative answer may be given in this assessment if there are sufficient historical field performance data available over a period of time that are adequate to assess the expected life cycle of the application, and if the climatological environment(s) of the historical record is comparable to the environment of the proposed application.

As in all the recommended assessments, the source of the data should be evaluated to determine that reported field testing and evaluations were undertaken by reputable organizations. It is also recommended as part of this assessment that the decision maker seek first-hand knowledge and advice from previous users of the proposed material in the intended application to confirm the findings and conclusions provided in written historical documentation. Direct contacts can be invaluable in providing specific information concerning the material and its proposed application. Data obtained in such a manner can yield information that may not be readily evident from a review of published reports.

Establish Performance Criteria

During the development of the screening plan, the decision maker will need to determine the criteria upon which an approval will be based. In this task, the decision maker may have a number of options. For example, where available, ASTM or AASHTO specifications or criteria imposed by local jurisdictions [e.g., State departments of transportation (DOTs)] can be used as performance criteria. In cases where no definitive criteria exist, the decision maker can compare the proposed material test results to that of a reference material (e.g., conventional construction material) to assess the relative properties of the proposed material versus that of a conventional material.

When evaluating new materials in highway construction applications, the passing or failing of one engineering or materials property test may not warrant a rejection of the material, particularly if performance testing suggests that the final product (e.g., an asphalt pavement) will perform satisfactorily. When a questionable situation arises, the decision maker can ultimately revert to Stage 2 laboratory evaluation to resolve uncertainties identified at the screening stage.

ENVIRONMENTAL, HEALTH, AND SAFETY

To undertake a Stage 1 environmental, health, and safety screening procedure, it is recommended that (1) a comparative source assessment be undertaken, which includes an analysis of the production or generation processes of the proposed and reference materials to verify that they originate from the same type of source, (2) a comparative materials properties assessment be undertaken, which includes an evaluation to determine whether the properties of the proposed and reference materials are sufficiently similar, and (3) a historical field performance assessment be undertaken, which includes a determination from historical records that the material will perform satisfactorily in the proposed application.

Figure 3-2 provides a flowchart highlighting the three steps in the environmental, health, and safety screen. Included in Figure 3-2 is reference to Table 3-2, which provides additional guidance in evaluating the material source, environmental, health, and safety properties, and field performance history during a Stage 1 screen.

Materials Source Assessment

The materials source screening test method presented in Figure 3-2 and Table 3-2 is similar to the materials source screening test method presented for the engineering materials source screen in Figure 3-1 and Table 3-1. It requires that sufficient information be presented by the applicant to permit the decision maker to determine that the proposed material is or will be generated and processed in a manner similar to the historical reference material or to the process stream, and that changes in the production, generation, or post-production operations will not impact the quality of the proposed material with respect to the intended application.

If the quality of the feedstock material in any commercial or industrial operation is altered, one can expect some modification in the quality of the recycled material generated or produced in the process. For example, if the feedstock material for wood chips used in a soil cover or erosion control application is switched from a tree service supplier that provides clean chips to a supply from a pallet recycling facility that processes industrial pallets, the environmental quality of the chips can be expected to change.

Many commercial and industrial operations periodically alter their production processes. Such modifications could impact the recycled material quality. For example, an increase or decrease in the level of fluxing agent in a steel mill, or the introduction of a new binder used in a foundry casting operation, or changes in the level of scrubber reagents used in an air pollution control system of a fuel combustion process can all be expected to impact the quantity and, in some cases, the environmental quality of the by-product material generated.

After recycled materials are generated or produced, they may be subjected to processing (e.g., crushing and screening), conditioning (e.g., moisture or chemical addition), or storage (e.g., short- and long-term) that could impact the physical and chemical characteristics of the material. The decision maker should request from the applicant sufficient data to characterize the expected variability in the feedstock materials and production and post-production operations, and the resultant impact of the respective variability in the recycled material quality. If the data are insufficient, the decision maker may request that a quality control program be implemented to ensure that the final recycled material quality is not significantly impacted by the referenced variations. Illustrative examples of statistical methods that can be used as a guide for such an assessment are outlined in Chapter 9.

Environmental, Health, and Safety Properties Data

The comparative environmental, health, and safety properties assessment, presented in Figure 3-2 and Table 3-2, requires that the applicant provide sufficient data to the decision maker to demonstrate that the proposed and reference materials exhibit comparable environmental properties and conform to specifications established by the State or local government. If proposed material data are unavailable (i.e., in a case where the by-product material has not yet been produced), the decision maker must be satisfied that both the proposed and reference

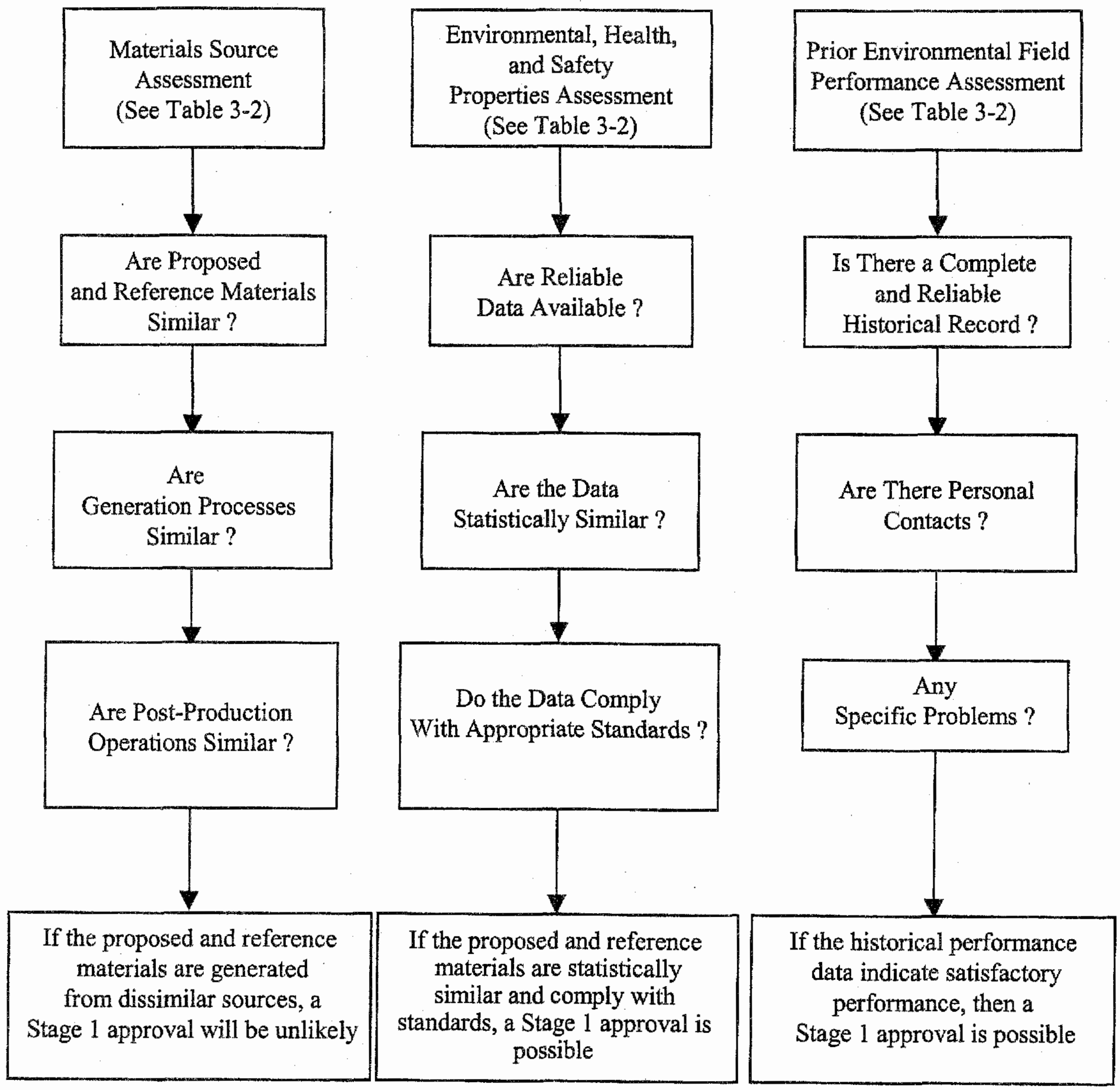

Figure 3-2. Stage 1 environmental, health, and safety properties screening flowchart.

materials will exhibit the same properties based solely on the presentation of information provided in the materials source assessment.

Historical Environmental, Health, and Safety Field Performance Data

As part of the evaluation process, the decision maker should ensure that adequate environmental property data are available to make an affirmative decision regarding the proposed application,

Table 3-2. Stage 1 environmental, health, and safety screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	
Material Source	Determine whether the proposed material is generated from the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☐ N☐ U☐
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to that of the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☐ N☐ U☐
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☐ N☐ U☐
Environmental Properties	Assess whether there are sufficient data to compare the environmental properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate environmental property data available for both the proposed and reference materials, and are the data reliable?	Y☐ N☐ U☐
		2. Can it be determined that the proposed and reference materials have statistically similar environmental properties that are in conformance with the specifications of the proposed application, and are they comparable?	Y☐ N☐ U☐

Table 3-2. **Stage 1 environmental, health, and safety screening checklist (continued).**

Parameter	Test Method	Evaluation Criteria[1]	
Field Performance	Determine whether the reported historical data provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	Y☐ N☐ U☐
		2. Are there personal contacts (regulators or scientists with experience) available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	Y☐ N☐ U☐
		3. Were there any specific problems or difficulties reported, and were the reported problems satisfactorily addressed in previous investigations to warrant a Stage 1 approval?	Y☐ N☐ U☐

1. Y = Yes, N = No, U = Unknown

that the sample statistics of the environmental property data provided by the applicant for the proposed and reference materials are comparable, and that they are within the design criteria of the specifying jurisdiction. Illustrative examples of statistical methods used to compare historical data to standards or the performance of reference materials is given in Chapter 9.

The historical environmental, health, and safety field performance assessment, presented in Figure 3-2 and Table 3-2, requires that an evaluation be undertaken of the field performance of the reference material. An affirmative answer may be given in this assessment if there are sufficient historical field performance data available, over a period of time that is adequate to assess the expected life cycle of the application, and if the climatological environment(s) of the historical record is comparable to the environment of the proposed application. As in all the recommended assessments, the source of the data should be evaluated to determine that reported field testing and evaluations were undertaken by reputable organizations and that appropriate quality assurance and control procedures were used in the data collection process. It is also recommended as part of this assessment that the decision maker seek first-hand knowledge and advice from previous users and regulators in other States of the proposed material in the intended application to confirm the findings and conclusions provided in written historical documentation. Direct contacts can be invaluable in providing specific information concerning the material and its proposed application. Data obtained in such a manner can yield information that may not be readily evident from a review of published reports.

Establish Performance Criteria

During the development of the screening plan, the decision maker will need to determine the criteria on which approval will be based. The selection of appropriate criteria can be based on existing environmental, health, and safety criteria that can be used as yardsticks. These may include clean soil criteria, which are used as guidelines for contaminated site remediation, ground water standards, surface water standards, and indoor or work place air quality standards or standards developed by States as part of their beneficial use determination (BUD) process.

The values in these criteria or standards have been established by Federal and State agencies to minimize likely impacts to receptors on the basis of ingestion, inhalation, or dermal exposure. Inherent here is the assumption that the exposure scenarios anticipated during the design life of the application and during subsequent reuses is similar to those used to articulate the above risk-based standards. The relevance of this assumption should be assessed in each instance, since the suitability of the reference criteria are critical to a good evaluation.

Suitable reference materials (e.g., traditional construction materials) can be used as controls to compare the environmental performance of the proposed material and a reference material or series of reference materials. Inherent here is the assumption that these reference materials are acceptable from an environmental and health risk perspective.

Chapter 10 provides a listing and description of available web sites (as of this writing) that can be used to access information on assessment methods and criteria that can be used in a Stage 1 evaluation.

RECYCLING

Since the current trend in managing recycled materials generated during the demolition of existing pavements is to reclaim and recycle as much material as possible, it is important to assess whether the introduction of new materials into roadway structures could adversely impact the potential for recycling the pavement (containing the recycled material) in a secondary (post-service life) application. In a Stage 1 recycling screen, it is recommended that both the applicant and the decision maker consider the potential impact that using the proposed material might have on their subsequent reuses.

It is recommended that the applicant and decision maker proceed with such an evaluation by (1) identifying the most likely subsequent use or uses of the product, (2) evaluating the impact of the proposed material on the engineering and materials properties of the secondary product, and (3) evaluating the impact of the proposed material on the environmental, health, and safety properties of the secondary product.

Figure 3-3 provides a flowchart highlighting the three steps in a recyclability evaluation. Included in Figure 3-3 is reference to Table 3-3, which provides additional guidance on evaluating the engineering, environmental, and worker health and safety issues during the Stage 1 screen.

Identify Likely Subsequent Reuses

When roadway construction materials are recycled, they are generally recycled into products that will take maximum advantage of the inherent economic value of the properties of the original product. For example, since recycled asphalt pavements (RAP) contain high-quality aggregates as well as asphalt cement, it is more desirable to use RAP in new pavements where the value of high-quality aggregate and the asphalt cement may be taken advantage of, as opposed to utilizing the RAP as a granular base material, where lower-quality aggregates and aggregates without asphalt cement might suffice. Previous studies by the FHWA have identified a hierarchy of roadway material uses that identify potential secondary product applications (*User Guidelines for Waste and By-Product Materials in Pavement Construction*, FHWA-RD-97-148, 1998). This hierarchy can be used in a Stage 1 screen to identify potential post-service life applications for various highway construction materials. Table 3-4 presents a listing of these roadway material uses highlighting the original or initial applications and potential subsequent applications.

To identify potential subsequent applications, the applicant or decision maker enters the table on the left with the initial application and follows the row to the right of the initial application to select all potential secondary or post-service life applications. For example, a recycled hot mix asphalt concrete pavement could potentially be used in a cold mix, seal coat or surface treatment, as a stabilized base, granular base or embankment or fill material (some jurisdictions may prevent its use in an embankment or fill because of the presence of asphalt cement in the

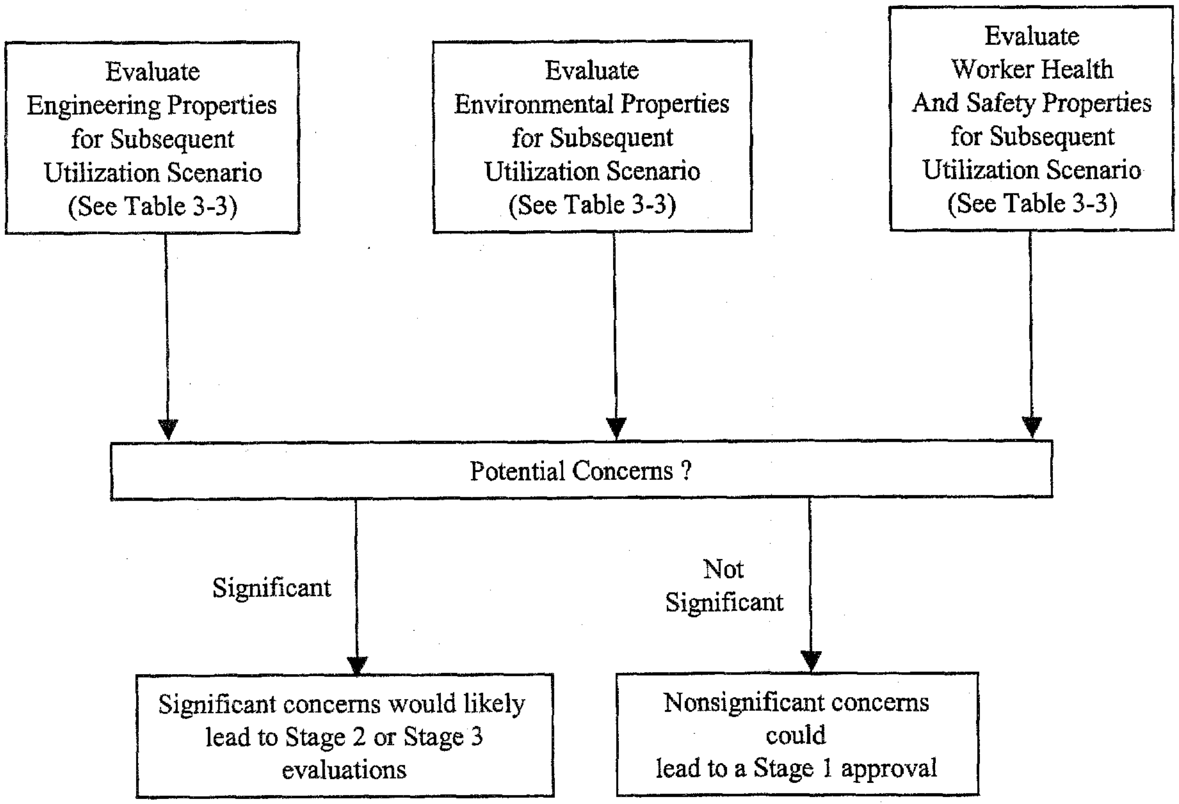

Figure 3-3. Recycling screening flowchart.

recycled hot mix). A recycled portland cement concrete pavement could be used in new portland cement concrete pavements, as a flowable fill aggregate, in a stabilized base or granular base, or as an embankment or fill material (recycled portland cement concrete pavements have also been sparingly used in asphalt pavement construction). A granular base or subbase aggregate material can be utilized as a flowable fill aggregate, a stabilized or granular base, or as an embankment or fill material.

Impact on Engineering and Materials Properties

Because of the hierarchy of uses in which materials are generally categorized, in most cases materials that have been used in an initial application will be suitable for use in a secondary application that requires lower quality materials. There can be instances, however, in which degradation of the proposed material during its service life or post-service life processing might alter the engineering properties of the original material and as a result compromise its use in a secondary application. This can occur in particle strength (blast furnace slag, municipal waste combustor ash) might degrade during its service life or post-service life processing, resulting in secondary products with higher fines content than anticipated; or when combustible products (rubber, carpet fiber) are introduced into products that may require high temperature secondary processing operations (asphalt plant drying).

Table 3-3. Stage 1 recycling screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	Y	N	U
Engineering Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the engineering quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the production process during a post-service life application?	☐	☐	☐
		2. Could the proposed material properties be altered during either its service life or post-service life processing to such an extent that it could significantly impact the properties of the secondary material?	☐	☐	☐
Environmental Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the environmental quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the environment (air, water, or soil quality) during post-service life processing if introduced into a secondary application?	☐	☐	☐
		2. Could the proposed material adversely impact the environment (air, water, or soil quality) during its post-service life use if introduced into a secondary application?	☐	☐	☐
		3. Could the proposed material adversely impact the environment (air, water, or soil quality) if disposed of as construction and demolition debris after its initial service life?	☐	☐	☐
Worker Health and Safety Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the worker health and safety properties of the product if used in a secondary application at the completion of its useful service life?	1. Could harmful fugitive dust or volatile gaseous emissions resulting from the use of the proposed material impact worker health or safety during post-service life processing or construction activities?	☐	☐	☐
		2. Could the use of the proposed material create a hazard to the physical safety of workers during post-service life processing or construction activities?	☐	☐	☐

1. Y = Yes, N = No, U = Unknown

Table 3-4. Recycled material recycling matrix.

Initial Application[1]	Potential Subsequent Reuse Application[2]												
	Hot Mix Asphalt Aggregate	Cold Mix Asphalt Aggregate	Seal Coat or Surface Treatment Aggregate	Asphalt Cement Modifier	Mineral Filler	Portland Cement Concrete Aggregate	Portland Cement Concrete Mineral Admixture	Flowable Fill Aggregate	Flowable Fill Pozzolan or Initiator	Stabilized Base or Subbase Aggregate	Stabilized Base Pozzolan, Initiator or Additive	Granular Base or Subbase Aggregate	Embankment or Engineered Fill
ASPHALT PAVING													
Hot Mix Asphalt Aggregate	•	•	•							•		•	•
Cold Mix Asphalt Aggregate	•	•	•							•		•	•
Seal Coat or Surface Treatment Aggregate			•							•			•
Asphalt Cement Modifier	•	•	•							•		•	•
Mineral Filler	•	•	•							•		•	•
PORTLAND CEMENT CONCRETE													
Portland Cement Concrete Aggregate						•		•		•		•	•
Portland Cement Concrete Mineral Admixture						•		•		•		•	•
FLOWABLE FILL													
Flowable Fill Aggregate								•		•			•
Flowable Fill Pozzolan or Initiator								•		•			•
STABILIZED BASE													
Stabilized Base or Subbase Aggregate								•		•			•
Stabilized Base Pozzolan, Initiator or Additive								•		•			•
UNBOUND AGGREGATE AND FILL													
Granular Base or Subbase Aggregate								•		•		•	•
Embankment or Engineered Fill										•			•

1. Represents original proposed material application.
2. Represents potential secondary uses of the excess material after the original service life. (Dots identify potential secondary application.)

Impact on Environmental, Health, and Safety Properties

From an environmental health and safety perspective, when recycled materials are incorporated into construction materials, the encapsulating effect of the engineered product is sometimes used to justify the material application (leaching and dust emission problems can be mitigated by such encapsulation). Post-service life processing that can alter the structural integrity of the original product could modify the encapsulating properties of the original product, introducing new environmental exposure pathways. This is particularly noteworthy in applications where the original material was used as part of a bound (concrete) product, but will be used as an unbound product (granular fill material) in a post-service life application.

Additionally, introducing materials with potentially harmful chemical or physical properties into an engineered product could result in potential safety problems to workers who must handle the material during post-service life recycling or construction operations. Fugitive dust, volatile emissions, or contact with chemically or physically abrasive materials are some of the concerns that should be considered.

IMPLEMENTATION

While some recycling strategies may appear to be technically and economically sound, the degree of difficulty that may be encountered in actually implementing the proposed recycling strategy can exceed that which either the applicant or the decision maker may have anticipated. It is therefore recommended that an applicant and decision maker consider, in a Stage 1 screen, the degree of difficulty that might be involved in implementing the proposed strategy. This evaluation procedure is not intended to establish a clear approval or rejection rating. It is primarily intended to increase the awareness of both the applicant and decision maker to some of the potential constraints that may be encountered while seeking to commercialize the proposed recycling strategy.

To undertake a Stage 1 implementation screen an evaluation is needed to assess the institutional, political, and public acceptability of the proposed option.

It is recommended that the applicant and decision maker undertake such an evaluation by (1) assessing the degree of difficulty required to gain final acceptance of the material and its proposed application by the technical community, (2) assessing the degree of positive support that one might expect from public officials, and (3) assessing the degree to which the public will look favorably or unfavorably on the proposed application. Figure 3-4 provides a flowchart highlighting the three steps in the Stage 1 implementation screen. Included in Figure 3-4 is reference to Table 3-5, which provides additional guidance in evaluating the institutional, political, and public acceptability issues.

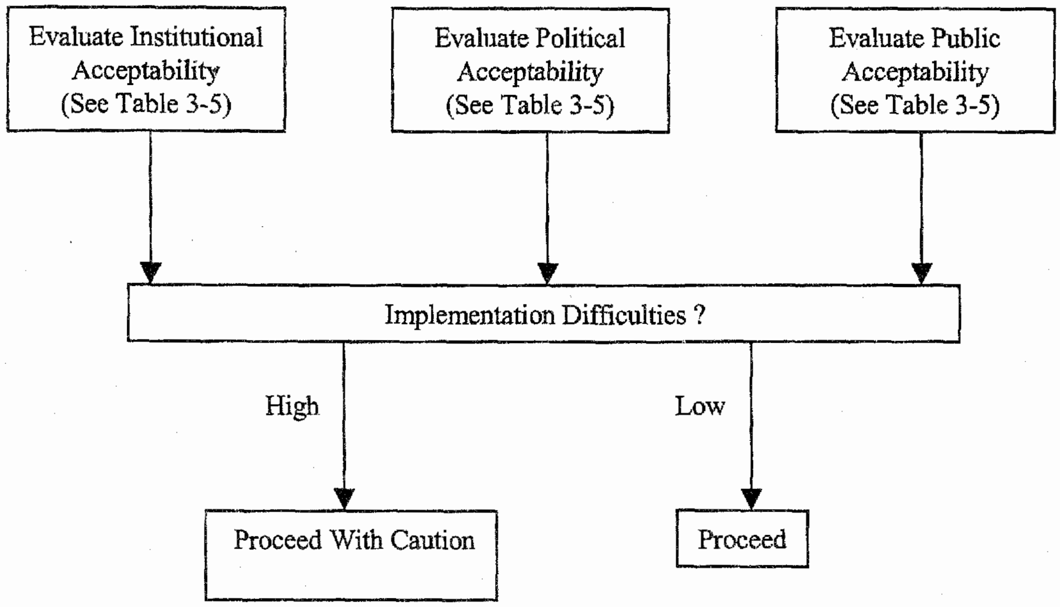

Figure 3-4. Stage 1 implementation screening flowchart.

Institutional Acceptability

Institutional acceptability is a factor intended to account for the degree of technical difficulty that might be encountered while attempting to move a new material application into a commercial application. The evaluation criteria are presented in Table 3-5 in the form of a checklist that includes four issues. Each of the four issues can be given a high, medium, or low rating.

The first issue listed requires that the evaluator rate the degree of difficulty that will be encountered in seeking to incorporate the proposed material into local construction specifications as an alternate material for use. This will require an assessment of the data needs and steps required to modify these specifications. A high rating for this issue would suggest that a greater degree of difficulty is required than a medium or low rating.

The second issue requires the evaluator to rate the degree of difficulty that will be encountered in seeking to gain environmental approvals (relevant beneficial use permits) for the proposed application. A high rating would suggest a greater degree of difficulty than a medium or low rating.

The third issue requires the evaluator to rate the degree to which engineers might be willing (or reluctant) to specify the material in the proposed application. A material for which there is some uncertainty regarding engineering or environmental performance can be expected to have less favor with most engineers. A high rating would suggest greater reluctance by engineers to specify the material than a medium or lower rating.

Table 3-5. Stage 1 implementation screening checklist.

Parameter	Test Method	Evaluation Criteria[1]			
Institutional Acceptability	Consider the probability that the regulatory community will approve and the technical community will accept and utilize the material in the proposed application.	1. Rate the degree of difficulty that can be anticipated in obtaining approval to incorporate the material-application match into existing construction specifications.	H ☐	M ☐	L ☐
		2. Rate the degree of difficulty that can be anticipated prior to the receipt of environmental approvals from regulatory agencies.	H ☐	M ☐	L ☐
		3. Rate the degree of reluctance that engineers might have in specifying the material in the proposed application.	H ☐	M ☐	L ☐
		4. Rate the degree of reluctance that contractors might have in utilizing the material in the proposed applications.	H ☐	M ☐	L ☐
Political Acceptability	Consider the degree to which public officials will support or impede the proposed application.	1. Rate the degree to which political opposition could impede the application.	H ☐	M ☐	L ☐
Public Acceptability	Assess the degree to which the public will accept the proposed material-application strategy.	1. Rate the degree to which the public opposition due to perceived environmental, health, safety, or economic impacts could impede the application.	H ☐	M ☐	L ☐

1. H = High, M = Medium, L = Low

The fourth issue is intended to focus the evaluator on the degree to which contractors might be willing to use the material. Materials that require new construction or quality control procedures are likely to be less desirable to contractors. A high rating would represent greater reluctance by the contractor than a medium or lower rating.

Political Acceptability

Political acceptability is a factor intended to account for the expected level of support that one might receive from public officials for the proposed material-application use. The primary issue in such an evaluation is the significance or impact that the proposed application might have in solving a high-profile material management problem. Positive political support can also be expected to facilitate institutional constraints that relate to regulatory and permit approvals.

The evaluation criteria are presented in Table 3-5 in the form of a checklist that includes one issue: To what degree is political opposition anticipated? If the proposed material can provide relief for a high-profile material management problem in a cost-effective, environmentally beneficial or neutral manner, then it is likely that support from public officials will be forthcoming. On the other hand, if the application is a low-profile issue, with little impact on the voting community, it is unlikely that significant public support will be forthcoming. This issue can be given a high, medium, or low rating, where a high rating represents a greater degree of political opposition than a medium or low rating.

Public Acceptability

Public acceptability is a factor intended to address the real or perceived reaction that the public may have to the proposed recycling strategy. Adverse public reaction to a proposed material-application strategy can be expected, in most cases, to erode political and institutional support.

The evaluation criteria are presented in Table 3-5 in the form of a checklist that includes one issue: To what degree will the public oppose the project based on perceived environmental, health, safety, or economic impacts? This issue can be given a high, medium, or low rating. A high rating represents a greater degree of public opposition than a medium or low rating.

ECONOMIC

In a Stage 1 economic screen, the applicant should provide sufficient economic data to demonstrate to the decision maker that the proposed material can be utilized in a cost-effective manner and that the cost is competitive relative to conventional materials. The level of detail associated with an economic screen need only be of a general nature. The purpose is to eliminate or discourage applications in which the cost of utilizing the proposed material is significantly higher than that of conventional materials, without any apparent benefit.

It is recommended that the applicant and decision maker undertake such an evaluation by considering (1) the price that the contractor would pay to have the material delivered to the job site, (2) the material cost plus the cost of design and construction (including quality control), and (3) the annual cost of the installed product over the life of the product (including maintenance).

The material cost of the recycled material is the delivered price of the material toa the job site. To determine which of the above cost items will be of most use in examining the economic viability of a proposed recycling strategy, the decision maker should consider three potential scenarios: (1) if the installation cost and expected performance of the proposed material is equivalent to that of a conventional material, then the decision maker need only compare the material cost of the proposed versus that of conventional materials; (2) if the new material is used in an application where additional design, construction, and quality control procedures are warranted, then the decision maker should compare the installation cost associated with the proposed material with the installation cost associated with the use of conventional materials; and (3) if introducing the proposed material into the application alters anticipated maintenance cost or the expected service life of the product, then the decision maker should compare the life-cycle cost of the application when the proposed material is used with the life-cycle cost when conventional materials are used.

Figure 3-5 provides a flowchart highlighting these evaluation steps. Included in Figure 3-5 is reference to Table 3-6 where the three costs outlined above are presented as equations that can be used to calculate each respective cost and as evaluation criteria to assess whether the proposed material will be more or less costly than conventional materials.

Material Cost

The material cost of the recycled material is the delivered price of the material to the job site.

The material cost evaluation criteria are presented in Table 3-6 in the form of an inequality. The proposed material cost is compared with the known cost of a conventional material. If the proposed material cost is less than or equal to the delivered price of conventional materials, then the economic screen would yield a positive result.

Installation Cost

The installation cost when using a new material can be calculated by adding the material cost to the design and construction costs, as well as any special testing and inspection requirements.

The installation cost evaluation criteria are presented in Table 3-6 in the form of an inequality. The proposed material installation cost is compared with the installation cost that would be incurred if a conventional material was used. If the proposed material installation cost is less than or equal to the installation cost that would be incurred when using conventional materials, then the economic screen would yield a positive result.

INTRODUCTION

In a Stage 2 engineering and materials properties evaluation, a laboratory testing program must be developed that will provide sufficient data to demonstrate that the proposed material is suitable for use in the proposed application.

To undertake this Stage 2 evaluation, it is recommended that (1) an engineering test plan be prepared that delineates the samples to be tested and the tests to which the sample will be subjected, (2) acceptable engineering and materials specifications or performance criteria be established so that the decision-making process can be completed, and (3) the data be statistically evaluated to determine if specifications are met or if performance is similar to appropriate reference materials.

Figure 4-1 provides a flowchart highlighting the sequential steps in an engineering and materials properties Stage 2 evaluation. Included in Figure 4-1 is reference to Tables 4-1 through 4-12. These tables provide a listing of engineering and materials properties test methods for most of the applications that will be encountered in the highway environment (see List of Tables at the front of this report for all table titles and applications). Tables 4-1 through 4-12 contain three columns: (1) a comment column that provides a description of the purpose of the test and when the test should be used, (2) a criteria column that provides a description of available or suggested test criteria, and (3) a description and reference for potential test methods that could be used.

Included in the tables are both material testing recommendations and product testing recommendations. For example, Table 4-1 provides a listing of recommended tests to evaluate the quality of a new material proposed for use as an aggregate substitute in asphalt concrete paving mixtures. Table 4-3 provides a listing of recommended tests to evaluate the performance of the asphalt concrete product, which can include the proposed material blended with conventional materials and asphalt cement.

Inherent in the use of this detailed flowchart is that laboratory testing requires assessment of the engineering and materials performance of the proposed material as well as the engineering and materials performance of the product or the application it will be used in. Finally, it is important to consider engineering and materials performance in potential post-service life utilization scenarios. While these reuse scenarios cannot be precisely described, it is important to identify to the extent possible future engineering issues that may arise if the recycled material is reused.

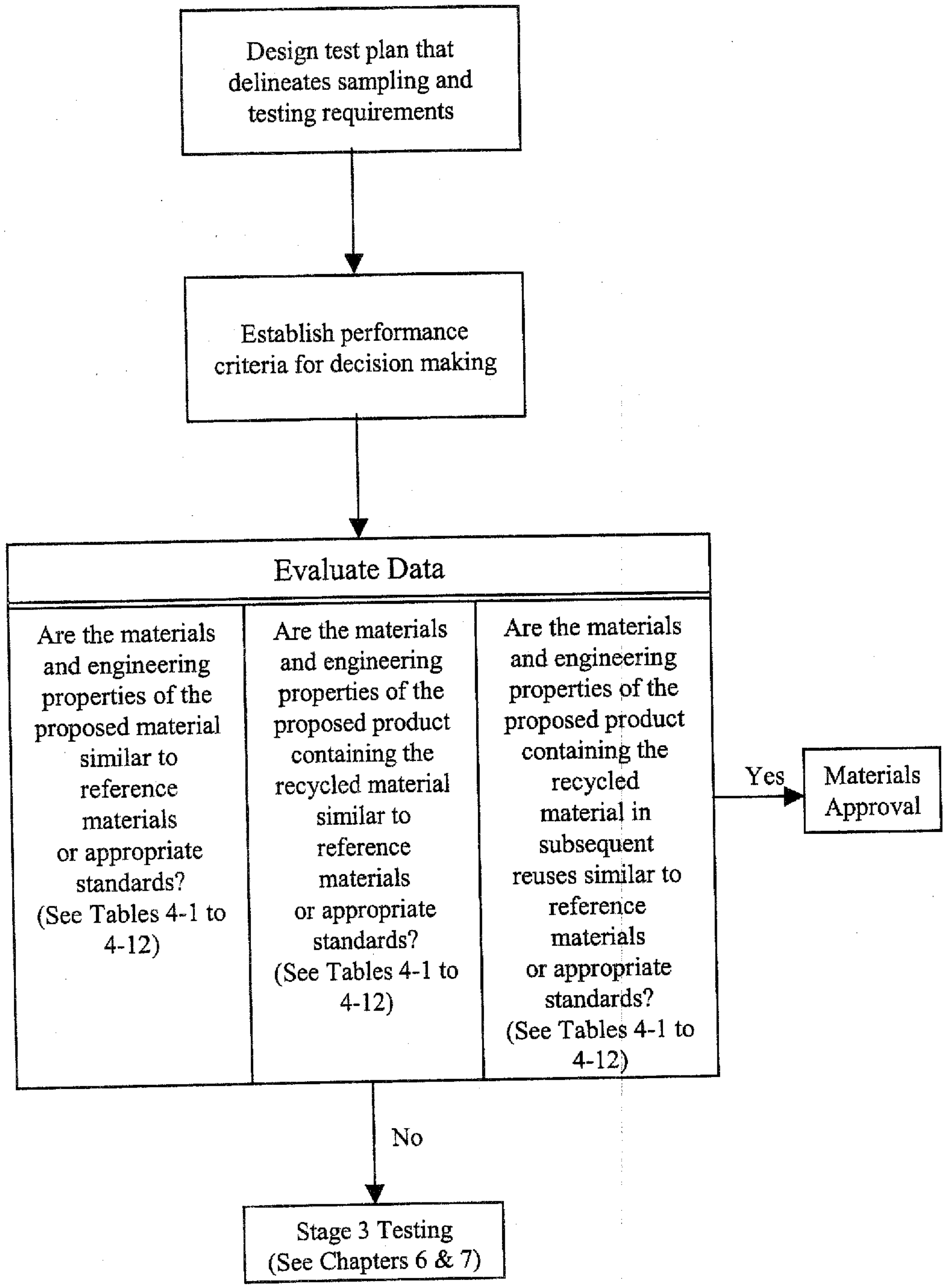

Figure 4-1. Engineering and materials properties laboratory testing flowchart.

LABORATORY ENGINEERING AND MATERIALS PROPERTIES TEST PLAN

The engineering and materials properties laboratory test plan should contain all appropriate test methods and procedures, including suitable reference materials to be used, criteria to be compared with, and statistical procedures to be used to compare the laboratory data with criteria or with the performance of the reference material.

Some recycled materials that may be proposed for use in a given application may have unique properties that do not readily lend the materials for testing as prescribed in the proposed test methods. For example, an applicant wishing to use scrap tire as an embankment material will have difficulty applying the test methods listed in Table 4-7 because of the relatively large size of the tire chips (25 to 75 mm), which cannot fit into the testing molds. Examples of properties and corresponding tests that are unsuitable include permeability (AASHTO T215 or ASTM D5084), compressibility (AASHTO T216 or ASTM D4186), bearing capacity (AASHTO T193), and shear strength (ASTM D2850, ASTM D3080, and ASTM D4767). In such cases alternative methods may be needed or design conditions will have to be based on field experience and construction specifications and not lab testing.

In other cases, not all of the engineering and materials properties and corresponding test methods will need to be evaluated for all proposed materials. For example, if it is known that a non-plastic material such as waste glass or blast furnace slag is being proposed for use as an aggregate or filler substitute in a stabilized base application (see Table 4-9), then Atterberg Limit testing to determine the plasticity of the material would be unnecessary.

In some instances additional tests not listed in the table may be warranted. For example, when reclaimed concrete material is used as a granular base it could have a tendency to clog down-gradient drainage systems containing geotextiles (sometimes wrapped around piping) because of the formation of calcium carbonate deposits (referred to as tufa deposits). In such instances some additional testing may be warranted to ensure that this deposition does not occur.

In summary, Tables 4-1 through 4-12 provide recommended guidance that the decision maker may be required to modify as needed for the particular material under consideration.

ESTABLISH ACCEPTABLE CRITERIA

During the development of the test plan, the decision maker will need to determine the criteria on which an approval will be based. Two approaches for evaluating the material properties are available. The first includes the use of ASTM or AASHTO specifications imposed by local jurisdictions (e.g., State DOTs), and the second, which is most applicable when such criteria are nonexistent, is the use of a reference material (e.g., conventional construction material) to assess the relative engineering properties of the proposed material versus that of the reference material.

Tables 4-1 through 4-12 provide a description of available criteria or recommendations on which the decision maker can make an evaluation.

When testing new materials in highway construction applications, the passing or failing of one engineering property test may not warrant a rejection of the material, particularly if performance testing suggests that the final product (e.g., an asphalt pavement) will perform satisfactorily. There may be instances where the proposed material yields poor particle strength results, but in a blended matrix product the material performs in an acceptable manner. When a questionable situation arises, the decision maker can ultimately revert to Stage 3 field evaluations to resolve laboratory uncertainties.

EVALUATE LABORATORY DATA FOR POSSIBLE APPROVAL

As illustrated in Figure 4-1, data comparisons between the recycled material and reference materials, or between recycled materials and appropriate ASTM, AASHTO, or State DOT standards will be required to evaluate the suitability of the application. Such comparative analyses are best undertaken using standard statistical procedures. Examples of such statistical procedures are presented in Chapter 9.

Table 4-1. Stage 2 laboratory testing recommendations for aggregate substitutes in asphalt concrete.

Engineering Property	Comment	Criteria	Test Method
Deleterious Materials	Potentially deleterious materials, such as organic matter, clays, debris, etc., could affect the strength and durability of an asphalt pavement. Such materials can be identified using a number of test procedures. Two such tests are the sand equivalent test method and petrographic examination. The sand equivalent test method is a Superpave recommended test method to assess the clay content of fine aggregates. For new materials that do not contain plastic fines, the test method is not applicable. A visual petrographic examination is recommended to identify whether the material is of uniform quality.	There are no ASTM or AASHTO specification limits for the sand equivalent test (ASTM D2419). A typical value of 45 to 50 is used for hot mix fine aggregate. ASTM C295 has no formal specification requirements and is used as an indicator to screen for problematic constituents.	Sand Equivalent, ASTM D2419 Petrographic Examination of Aggregates for Concrete, ASTM C295
Durability	Two types of tests are commonly used to evaluate the durability of a material. They are soundness tests and freeze-thaw tests. Soundness tests provide a measure of the susceptibility of the material to breakdown resulting from wetting and drying cycles. Freeze-thaw tests measure the susceptibility of the material to breakdown from freezing and thawing cycles.	Soundness tests are required as part of most jurisdictional specification requirements. ASTM D692 provides for an 18 percent maximum for magnesium sulfate soundness, and a 12 percent maximum for sodium sulfate soundness for coarse aggregates. ASTM D1073 Supplementary Requirement provides for a 20 percent maximum for magnesium sulfate soundness, and a 15 percent maximum for sodium sulfate soundness for fine aggregates. There are no ASTM or AASHTO specification requirements for freeze-thaw soundness. A maximum loss of 6 percent is generally considered to be appropriate for surface course hot mix asphalt coarse aggregate.	Magnesium or Sodium Sulfate Soundness, ASTM C88, AASHTO T104 Freeze-Thaw Soundness, AASHTO T103

Table 4-1. Stage 2 laboratory testing recommendations for aggregate substitutes in asphalt concrete (continued).

Engineering Property	Comment	Criteria	Test Method
Gradation	Sieve testing is necessary to establish blending requirements to meet the mix gradation specifications.	Specific gradation limits will vary from agency to agency, and for the intended use (e.g., binder course, surface or wearing course, friction course). Coarse aggregate grading limits are generally based on ASTM D448, AASHTO M43, and fine aggregate grading limits are based on ASTM D1073, AASHTO M29.	Sieve Analysis, ASTM C136, AASHTO T27
Particle Shape and Surface Texture	Particle shape and surface texture tests are important to establish whether the stability of the interlocking particle matrix can be expected to perform as quality aggregate material. Angular or cubical particles can be expected to yield favorable results while rounded particle shapes tend to be unsatisfactory. Three tests are available, which can be used to quantify particle shape and surface texture. These tests which are part of the Superpave mix design procedures include flat and elongated particle, uncompacted void content, and crushed fragment tests. The test(s) selected will depend on the requirements of the specifying agency.	There are no ASTM or AASHTO specification requirements for flat and elongated particles (ASTM D4791). The maximum percentage of flat and elongated particles in coarse aggregate recommended by Superpave depends on the density of traffic but cannot exceed 10 percent for roadways with annual equivalent single axle loads greater than 3 million. The uncompacted voids content of fine aggregate (AASHTO TP33) has a minimum specification value of 45 percent, with no specified maximum value. Some States have suggested adopting a maximum value of 52 percent to effectively limit the amount of flat and elongated particles in fine aggregate. The crushed fragment test (Penn DOT Method 621) has required minimum values for coarse aggregate angularity as a function of traffic level and position within the pavement.	Flat and Elongated Particles, ASTM D4791 Uncompacted Void Content of Fine Aggregate, ASTM C1252, AASHTO TP33 Crushed Fragments in Gravel (Coarse Aggregate Angularity), Penn DOT Method 621

Table 4-1. Stage 2 laboratory testing recommendations for aggregate substitutes in asphalt concrete (continued).

Engineering Property	Comment	Criteria	Test Method
Particle Strength	Particle strength can be assessed by LA abrasion testing, which is presently the standard test used by most specifying agencies in the United States. Glassy or light-weight porous materials tend to perform poorly when subjected to this test method, yet they may perform satisfactorily when used in field applications. The MicroDeval test is a test method developed in France during the 1960s and has been adopted by the Ministry of Transportation in Ontario, Canada (MTO). It is under evaluation in the United States as an alternative method to the LA Abrasion test. Recent evaluation of this test method has been undertaken by the Transportation Research Board (Project NCHRP 4-19). MicroDeval testing may be a more suitable test method than the LA abrasion test and can be used for evaluating fine aggregate particle strength down to 75 microns in size.	ASTM D692 provides for a 40 percent maximum abrasion loss for surface course, and a 50 percent maximum loss for binder course when subjecting aggregate to the ASTM C131 test procedure. There are no ASTM or AASHTO specification requirements for MicroDeval testing. Recent work by the Transportation Research Board (NCHRP 4-19) indicates that a maximum value of 18 percent is appropriate for surface course coarse aggregate, and 21 percent for binder course coarse aggregate. There are no ASTM or AASHTO specification requirements for MicroDeval testing. Recent work by the Transportation Research Board (NCHRP 4-19) indicates that a maximum value of 25 percent is appropriate for hot mix fine aggregate.	LA Abrasion, Small Size Aggregate, ASTM C131, AASHTO T96 Resistance of Coarse Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 618 Resistance of Fine Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 619
Specific Gravity and Absorption	Mix design procedures require that specific gravity be tested for aggregates used in the blend. Aggregate substitute materials with high absorption values will have higher demand for asphalt cement. Highly porous materials will typically yield high absorptive values.	There are no specific ASTM or AASHTO specification requirements for specific gravity and absorption. Aggregates having values greater than 2 percent are generally considered to be absorptive.	Coarse Aggregate, ASTM C127, AASHTO T85 Fine Aggregate, ASTM C128, AASHTO T84

Table 4-1. Stage 2 laboratory testing recommendations for aggregate substitutes in asphalt concrete (continued).

Engineering Property	Comment	Criteria	Test Method
Volume Stability	When a new material is introduced as an aggregate substitute, there is always some concern that the material may contain hydratable salts or potentially expansive reactants. ASTM D4792 is a test method that has been used to assess the dimensional stability of steel slag. Its use with other materials has not been fully tested.	At present ASTM D4792 has only been used for steel slag aggregates. Expansion limits have been established by various States and range from 1 to 2 percent.	Potential Expansion of Aggregates from Hydration Reactions, ASTM D4792

Table 4-2. Stage 2 laboratory testing recommendations for mineral filler substitute in asphalt concrete.

Engineering Property	Comment	Criteria	Test Method
Gradation	To be approved for use as a mineral filler in asphalt concrete pavement, a mineral filler substitute should comply with specified gradation requirements. These gradation requirements are designed to ensure the major fraction of the filler will not consist of particles with sizes greater than the film thickness of the asphalt (10-100 microns). The particle size of mineral filler is expected to conform to the required specifications.	Gradation requirements for mineral filler in road paving mixtures are defined in ASTM D242, AASHTO M17.	Sieve Analysis of Mineral Filler for Road and Paving Mixtures, ASTM D546, AASHTO T37
Plasticity	Substitute mineral filler material should exhibit low plasticity characteristics. Plasticity is typically characterized by Atterberg Limit Testing.	The Plasticity Index of the mineral filler should not be greater than 4, in accordance with ASTM D242, AASHTO M17 specifications.	Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM D4315

Table 4-3. Stage 2 laboratory testing recommendations for performance in asphalt concrete.

Performance Test	Comment	Criteria	Test Method
Superpave Level 1 and Level 2 Mix Designs (Asphalt Institute SP-2)	The Superpave mix design procedure contains a series of performance tests, the procedures of which are outlined in the corresponding test methods. Very little experience is available using Superpave mix design procedures for nonconventional materials.	The tests listed comprise the individual test methods that are part of the Superpave Mix Design procedure. The mixture is designed to meet the requirements for traffic and climate given in the Strategic Highway Research Program (SHRP) Superpave volumetric design procedure. AASHTO TP7 and TP9 are performance prediction tests that form part of Superpave Level 2 and 3 design procedure. Appropriate limits are determined using predicted performance for rutting and fatigue cracking based on traffic, and low temperature cracking based on years of service.	Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyratory Compactor, AASHTO TP4 Short- and Long-Term Aging of Bituminous Mixtures, AASHTO PP2 Evaluation of Axial and Shear Loading Characteristics of Compacted SGC Specimens Using the Superpave Shear Tester, AASHTO TP7 Creep Compliance and Strength at Low Temperatures Using the Indirect Tensile Tester, AASHTO TP9 Creep Compliance and Strength at Intermediate Temperatures Using the Indirect Tensile Tester, AASHTO TP9

Table 4-3. Stage 2 laboratory testing recommendations for performance in asphalt concrete (continued).

Performance Test	Comment	Criteria	Test Method
Marshall Mix Design (Asphalt Institute MS-2)	Most agencies in the United States utilize the Marshall mix design method, which entails laboratory methods designed to develop a suitable mixture using stability-flow and density-voids analyses. The design procedure involves the conduct of a number of test methods. When incorporating a substitute material (aggregate or filler) into a blend, a Marshall design if specified will be necessary to establish the optimum mix design, which will include the percentage of substitute material and asphalt requirements of the mix.	The tests listed comprise the test methods that make up the Marshall design procedure. Specifying jurisdictions usually define stability values, flow values, and air void requirements for paving mixes, dependent on the type of mix. Job mix formula guideline requirements are presented in ASTM D3515.	Quantitative Extraction of Bitumen from Bituminous Paving Mixtures, ASTM D2172, AASHTO T164 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures, ASTM D2041, AASHTO T209 Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures, ASTM D2726, AASHTO T166 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, ASTM D1559, AASHTO T245 Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures, ASTM D3203, AASHTO T269
Hveem Mix Design (Asphalt Institute MS-2)	Some jurisdictions (notably California) have utilized the Hveem mix design method, which is a laboratory procedure designed to develop information on cohesion and friction of specially prepared specimens. The design procedure involves the conduct of a number of test methods that determine the optimum asphalt content, a stabilometer value, cohesionometer value, and swell test results that are used for design purposes.	The suitability of a hot mix design is based on whether the mix properties can meet test result values that are specified in Asphalt Institute Manual MS-2 (Mix Design Methods for Asphalt Concrete and Other Hot Mix Types) for heavy, medium, and light traffic applications.	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus, ASTM D1560, AASHTO T246 Preparation of Bituminous Mixture Test Specimens by Means of California Kneading Compactor, ASTM D1561, AASHTO T247
Stripping Resistance (Moisture-Accelerated Damage) -	Once the design blend is selected or to assist in modifying the blend, the recommended procedure for evaluating moisture sensitivity (stripping problems) is the Modified Lottman Procedure. This procedure involves	Stripping resistance is measured by indirect tensile strength before and after subjecting specimens to weathering tests. A tensile strength ratio (the ratio of tensile strength after and prior to weathering) is specified by the	Modified Lottman Test, AASHTO T283

Table 4-3. Stage 2 laboratory testing recommendations for performance in asphalt concrete (continued).

Performance Test	Comment	Criteria	Test Method
Marshall and SHRP Procedure	conditioning of mix design specimens, subjecting the specimens to partial vacuum saturation followed by freeze-thaw cycles, and testing the specimens to evaluate the indirect tensile strength relative to a control sample. Glassy materials tend to be sensitive to moisture damage if introduced into a mix at high substitution rates (greater than 25 to 50 percent), or if coarse, glassy particles are introduced into the mix.	Superpave design procedure as a minimum of 80 percent. A minimum of 70 percent is typically used in conventional design procedures.	

Table 4-4. Stage 2 laboratory testing recommendations for aggregate substitutes in portland cement concrete.

Engineering Property	Comment	Criteria	Test Method
Deleterious Materials	Potentially deleterious materials such as organics, clay particles, friable particles, plastic fines, debris, etc., could affect the strength, curing time, weathering resistance, and volumetric stability of the mix. A visual petrographic examination is the simplest method to identify the presence of potentially deleterious materials in an unknown material. This procedure is used to identify potentially deleterious constituents in the concrete aggregate (potential alkali-aggregate reactive aggregates and poor quality rocks and minerals). Organic impurity testing is specified by many jurisdictions using colorimetric methods; however, a colorimetric test may not be suitable for materials that can mask the test solution color. Organic content testing can also be undertaken using methods that measure loss of weight after subjecting the sample to combustion temperatures. Clay lumps and friable particles are detrimental to concrete mixes and can be identified using ASTM C142 procedures.	There are no ASTM or AASHTO specification limits for the petrographic examination test procedures, ASTM C295. Concrete fine aggregates are specified to be largely free of organic material, and have a color of 3 or less in the Standard Color Plate as per ASTM C33. There are no specific criteria for organic matter, which is quantified by loss of weight due to combustion tests, but it is generally recommended that the organic content be limited to less than 5 percent by weight. AASHTO M80 limits the amount of clay lumps and friable particles in pavements from 3 to 5 percent depending on the severity of the exposure conditions.	Coarse Aggregate Petrographic Examination, ASTM C295 Organic Impurities, ASTM C40 Moisture, Ash and Organic Matter of Peat Materials, ASTM D2974 Clay Lumps, ASTM C142

Table 4-4. Stage 2 laboratory testing recommendations for aggregate substitutes in portland cement concrete (continued).

Engineering Property	Comment	Criteria	Test Method
Durability	Resistance to wetting and drying (AASHTO T104) and freezing and thawing (AASHTO T103) is imperative if the aggregate substitute material is to perform satisfactorily in a concrete mix. Soundness tests are required as part of most jurisdictional specification requirements.	AASHTO M80 specifies a maximum magnesium sulfate soundness loss of 18 percent for concrete coarse aggregate (12 percent for sodium sulfate soundness loss). AASHTO M6 limits the sodium sulfate soundness loss to 10 percent maximum for concrete fine aggregate (the limit for fine aggregate magnesium sulfate soundness loss is to be that which experience shows corresponds to the 10 percent sodium sulfate soundness loss, which is typically about 16 percent). There are no ASTM or AASHTO specification limits for freeze-thaw soundness in concrete aggregates. A specification limit for the coarse aggregate unconfined freeze-thaw loss after 5 cycles of 6 percent is specified by C.S.A. A23.1, which is a Canadian standard.	Magnesium or Sodium Sulfate Soundness, ASTM C88, AASHTO T104 Freeze-Thaw Soundness, AASHTO T103
Gradation	The size distribution of aggregate or aggregate substitute particles can affect the cementing material requirements, the water requirements, the workability, porosity, shrinkage, and durability of a concrete mix.	ASTM C33 provides grading limits generally applicable to fine and coarse aggregates used in portland cement concrete applications.	Sieve Analysis, ASTM C136, AASHTO T27
Particle Shape and Surface Texture	The particle shape and surface texture of both coarse and fine sized aggregates or aggregate substitutes can affect the properties of the mix. Flat and elongated particle testing and uncompacted void content testing are two methods that can be used to characterize particle shape. Rough textured, angular, or elongated particles require more water to produce workable concrete when compared with smooth or	There are no ASTM or AASHTO specification limits for flat and elongated particles in portland cement concrete. The effect of flat and elongated particles is typically not significant if limited to no more than about 15 percent. This uncompacted void test method is generally used for concrete fine aggregate. However, the test provides useful information related to fine aggregate shape when a recycled material is introduced, which is of interest for concrete	Flat and Elongated Particles, ASTM D4791 Uncompacted Voids Content, ASTM C1252, AASHTO TP33

Table 4-4. Stage 2 laboratory testing recommendations for aggregate substitutes in portland cement concrete (continued).

Engineering Property	Comment	Criteria	Test Method
	rounded particles, and as a result increase the cement content of the mix (to maintain the same water to cement ratio). Aggregate substitutes containing flat or elongated particles can be expected to reduce the hardened concrete strength. An angular and cubical material should exhibit acceptable results when subjected to this test method.	workability.	
Particle Strength	Particle strength can be assessed by Los Angeles abrasion testing, which is presently the standard test used by most specifying agencies in the United States. The MicroDeval test is a test method developed in France during the 1960s and has been adopted by the Ministry of Transportation in Ontario, Canada (MTO). It is under evaluation in the United States as an alternative method to the LA Abrasion test. MicroDeval testing may be more suitable than LA abrasion and can be used for evaluating fine aggregate (sand-size) particle strength.	AASHTO M80 specification limits the amount of LA Abrasion test loss to 50 percent. There are no ASTM or AASHTO specification limits for MicroDeval testing. The Ontario Ministry of Transportation in Canada limits the MicroDeval loss to 13 percent for coarse aggregate used in concrete pavements; 17 percent for structural concrete, sidewalks, curb and gutter and concrete base; and 20 percent for concrete fine aggregate.	Los Angeles Abrasion, Small Size Aggregate, ASTM C131, AASHTO T96 Resistance of Coarse Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 618 Resistance of Fine Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 619
Specific Gravity and Absorption	The absorption and surface moisture condition of an aggregate substitute material that is introduced in a concrete mix must be determined so that the water content of the concrete mix can be controlled.	There are no ASTM or AASHTO specification limits. These data are used to determine concrete mixture proportions in accordance with the American Concrete Institute (ACI) volumetric concrete mix design procedure.	Coarse Aggregate, ASTM C127, AASHTO T85 Fine Aggregate, ASTM C128, AASHTO T84
Volume Stability	It is important that concrete aggregate be volumetrically stable. Two tests are available that can be used to identify potential reactivity and expansion problems.	AASHTO M80 recommends a limit in the amount of expansion to a maximum of 0.2 percent after 1 year when using ASTM C342 and 0.05 percent in 3 months and 0.10 percent in a year when using ASTM C227. Specifications have been defined in Canadian	Volume Change of Cement-Aggregate Combinations, ASTM C342 Potential Alkali-Silica Reactivity by Accelerated Mortar Bar, ASTM C227

Table 4-4. Stage 2 laboratory testing recommendations for aggregate substitutes in portland cement concrete (continued).

Engineering Property	Comment	Criteria	Test Method
		Standards CSA A23.1, which limit mortar bar expansion in ASTM C227 to 0.14 percent after 14 days (0.30 percent after 28 days).	

Table 4-5. Stage 2 laboratory testing recommendations for performance in portland cement concrete.

Performance Test	Comment	Criteria	Test Method
Air Content	When substitute materials are introduced into concrete mixes, the air content of the mix could be altered. Since it is important for cured concrete to have adequate entrained air to withstand cycles of freezing and thawing, air content should be monitored. There are three methods available for quantifying air content. They include the air voids content method, the pressure method, and the volumetric method. The air voids content test is a test method that is undertaken on hardened concrete and is influenced by methods of placement, consolidation, and curing. The pressure and volumetric methods are carried out on fresh plastic concrete. The volumetric method is suitable for normal or lightweight materials.	For air-entrained concrete designed in accordance with ACI 201.2R and 211.1, the paste-air ratio is usually in the range of 4 to 11, the specific surface is in the range of 24 to 43, and the spacing factor is 0.10 to 0.20 mm. The recommended total air content of air-entrained concrete is a function of the nominal maximum size of the aggregate and exposure condition (mild, moderate, severe), and is given in ASTM C94.	Determination of Air-Void Content in Hardened Concrete, ASTM C457 Air Content of Fresh Concrete by the Pressure Method, ASTM C231, AASHTO T152 Air Content of Fresh Concrete by the Volumetric Method, ASTM C173, AASHTO T196

Table 4-5. Stage 2 laboratory testing recommendations for performance in portland cement concrete (continued).

Performance Test	Comment	Criteria	Test Method
Consistency	Consistency is a measure of the ability of freshly mixed concrete to flow. The slump test can provide an indication of the consistency of the mix. The higher the slump the wetter the mixture. Workability is a measure of how easy or difficult it is to place, consolidate, and finish the concrete within forms without harmful segregation. The slump test is an indicator of workability when assessing similar mixtures. Bleeding is the movement of water to the top surface of freshly placed concrete and is due to settlement of aggregate or cement in the concrete. Concrete should be workable but not segregate or bleed excessively.	There are no ASTM or AASHTO specification requirements for slump or bleeding. For pavements and slabs some local jurisdictions specify slumps between 1 inch (2.54 cm) and 3 inches (7.62 cm). These parameters should be examined during the mix design.	Slump of Hydraulic Cement Concrete, ASTM C143, AASHTO T119 Bleeding of Concrete, ASTM C232, AASHTO T158
Durability	Hardened concrete must be capable of resisting damage from freezing and thawing, wetting and drying, and scaling. When a substitute material is introduced into a mix, tests should be undertaken to evaluate the durability of the mix. Two test methods are available to evaluate durability relating to freezing and thawing and scaling. They include ASTM C666 and ASTM C131.	There are no ASTM or AASHTO specification requirements for freezing, thawing, or scaling. The Ontario Ministry of Transportation, to mitigate D-line cracking of concrete pavements, limits the maximum average length change to 0.035 percent after 350 cycles in ASTM C666 and the maximum permitted scaling loss in ASTM C131 to 0.8 kg/m sq after 50 cycles.	Resistance to Rapid Freezing and Thawing, ASTM C666 Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals, ASTM C131, AASHTO T96

Table 4-5. Stage 2 laboratory testing recommendations for performance in portland cement concrete (continued).

Performance Test	Comment	Criteria	Test Method
Hydration and Setting	When substitute materials are introduced into concrete mixes, the overall setting time of the concrete product could be impacted. Knowledge of the rate of reaction is important to determine hardening time. Unless the reclaimed concrete material contains deleterious materials, setting time should not be adversely impacted by the introduction of this material. Setting time can be compared to control mixes to determine the relative impacts of introducing new materials into the mix. The hydration and setting of concrete should be examined during the mix design.	There are no ASTM or AASHTO specification requirements.	Hydration and Setting By Penetration Resistance, ASTM C403
Specific Gravity and Absorption	The density of concrete mixes will depend on the amount and unit weight of any material introduced into the mix. The impact on the density and yield of the concrete should be evaluated during the mix design.	There are no ASTM or AASHTO specification requirements for specific gravity and absorption. The data are used to determine mass/volume conversions for concrete and to determine conformance with concrete specifications.	Gravity, Absorption and Voids in Hardened Concrete, ASTM C642

Table 4-5. Stage 2 laboratory testing recommendations for performance in portland cement concrete (continued).

Performance Test	Comment	Criteria	Test Method
Strength	Compressive strength is the most common test of concrete strength; however, most concrete pavements are designed based on flexural strength of the concrete or the modulus of rupture, which can be measured by third point loading or splitting tensile strength tests. Compressive strength, depending on the specifying agency, can be correlated with flexural strength.	ASTM C94 specifies the testing frequency and tolerances for concrete strength. The compressive strength for a given mix is a function of the mix design. The flexural strength of concrete is a mix design consideration. There are no specified flexural or tensile strength requirements in ASTM or AASHTO specifications. Flexural strength and splitting tensile strength is of interest for concrete that will be subjected to bending (flexure) such as beams, floor slabs, and concrete pavements.	Compressive Strength of Cylindrical Specimens, ASTM C39, AASHTO T22 Simple Beam with Third Point Loading, ASTM C78, AASHTO T97 Splitting Tensile Strength, ASTM C496, AASHTO T19
Volume Stability	Concrete mixes must be volumetrically stable and not expand due to chemical reactions or shrink excessively upon drying. When substitute materials are introduced into concrete mixes, volume stability tests should be undertaken. Two potential ASTM test methods are available. They include ASTM C157 and ASTM C1105. Prediction of shrinkage, based on similar tests, is discussed in detail in ACI 209R.	There are no ASTM or AASHTO specification requirements for volume stability. During the conduct of ASTM C1105, a given cement-aggregate combination can be classified as potentially deleteriously reactive if the average (or 6 tests) expansion is 0.015 percent at 3 months; 0.025 percent at 6 months, or 0.030 percent at 1 year.	Length Change of Hardened Hydraulic-Cement Mortar and Concrete, ASTM C157 Length Change due to Alkali-Carbonate Rock Reactivity, ASTM C1105

Table 4-6. Stage 2 laboratory testing recommendations for aggregate substitutes in granular base.

Engineering Property	Comment	Criteria	Test Method
Particle Strength	Materials that are used as a granular base should have sufficient strength to resist excess breakdown. Many jurisdictions will specify minimum requirements. Particle strength can be assessed by LA abrasion testing, which is presently the standard test used by most specifying agencies in the United States. The MicroDeval test is a test method developed in France during the 1960s and has been adopted by the Ministry of Transportation in Ontario, Canada (MTO). It has been under recent evaluation in the United States by the Transportation Research Board (NCHRP 4-19) as an alternative method to the LA Abrasion test. MicroDeval testing may be more suitable than LA abrasion, and can be used for evaluating fine aggregate particle strength down to 75 microns in size.	There are no ASTM or AASHTO particle strength specification requirements for granular base and subbase. Most agencies specify a maximum Los Angeles abrasion loss ranging between about 50 and 60 percent for conventional granular materials. The Ontario, Canada, Ministry of Transportation specifies a maximum Micro Deval test loss of 25 percent for the coarse portion of granular base material, and 30 percent for granular subbase.	Los Angeles Abrasion, Small Size Aggregate, ASTM C131, AASHTO T96 Resistance of Coarse Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 618 Resistance of Fine Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 619
Moisture Density Characteristics	Most specifications will require that a granular base be constructed with a specified compacted density. Two tests are available to characterize compaction. They include AASHTO T99 and T180.	The moisture-density relationship must be established to determine the compaction characteristics of the granular base/subbase, and as the reference density for compaction (typically specified to be at least 95 percent of the Standard Proctor maximum dry density in most State specifications). The modified Proctor test is usually specified where the granular base/subbase must have higher shear strength and hence must be more dense.	Standard Proctor, ASTM D698, AASHTO T99 Modified Proctor, AASHTO T180

Table 4-6. Stage 2 laboratory testing recommendations for aggregate substitutes in granular base (continued).

Engineering Property	Comment	Criteria	Test Method
Permeability	A number of permeability tests are available for quantifying permeability or hydraulic conductivity. Some granular bases are dense graded by design (low permeability) and some are open graded (high permeability). The specific test method selected in many cases will be determined by the grading specification or specifying agency.	There are no specific permeability requirements for granular base or subbase materials. However, when such materials are required to be free-draining, the permeability should not be less than about E-02 to E-03 cm/sec.	Constant Head Permeability, ASTM D2434, AASHTO T215 Flexible Wall Triaxial Permeability Test, ASTM D5084
Gradation	The gradation of a material influences the stability, drainage, and frost susceptibility of the base. Gradations are typically specified for granular base materials. If a new material cannot, by itself, meet the specified gradation, then blending may be required.	Gradation limits are defined by the specifying jurisdiction and for the intended use (base, subbase). Grading limits used by specifying agencies are generally based on ASTM D2940 or AASHTO M147.	Sieve Analysis, ASTM C136, AASHTO T27
Durability	In situations where free draining (open-graded) bases are specified, durability testing is recommended to preserve the drainage capability of the material. Magnesium and sodium soundness tests provide a measure of the susceptibility of the material to breakdown due to hydration reactions within the pore spaces of the aggregate. The freeze-thaw soundness test is a measure of the susceptibility of the material to breakdown due to variation in temperature.	There are no ASTM or AASHTO specification limits for the durability of aggregates in granular base applications. Some jurisdictions have specified respective maximum soundness and freeze-thaw losses in the range of 15 percent.	Magnesium or Sodium Sulfate Soundness, ASTM C88, AASHTO T104 Freeze-Thaw Soundness, AASHTO T103

Table 4-6. Stage 2 laboratory testing recommendations for aggregate substitutes in granular base (continued).

Engineering Property	Comment	Criteria	Test Method
Base Stability	A granular base should have high stability, particularly if it is being used as a supporting structure for an overlying pavement structure. Many jurisdictions utilize the California Bearing Ratio (CBR) test as a measure of base stability.	High quality, dense graded aggregate has a California Bearing Ratio (CBR) value of about 100 percent or higher. Many granular base specifications stipulate a minimum CBR value of 80 percent (the Asphalt Institute). The National Stone Association and U.S. Department of Defense apply a CBR value of 100 percent to graded crushed aggregate. Most aggregate subbase specifications require minimum CBR values in the range of 20 to 50 percent.	California Bearing Ratio, ASTM D1883, AASHTO T193
Deleterious Materials	The presence of deleterious materials such as plastic fines, organic matter, or extraneous debris that might be present in substitute materials could reduce the load carrying capacity and ultimately the expected performance of a granular base. The Atterberg limit test is the most widely used test for characterizing plasticity. Other tests (e.g., sand equivalent test) might be used if required by the specifying jurisdiction. Petrographic examination (ASTM C295) is recommended to assist in identifying the types and quantities of extraneous debris. Organic content testing ASTM D2974 or equivalent) is recommended to identify the extent of organic matter. Volumetric expansion testing is also recommended (ASTM D4792) to ensure that no unforeseen expansive reactions will occur if a	ASTM D2940 specifies that a material passing a 0.425 mm (No. 40) sieve for granular base and subbase should have plasticity indices no greater than 4 and 6, respectively. ASTM D2940 specifies that a material passing a 0.425 mm (No. 40) sieve for granular base and subbase should have sand equivalent values of not lower than 35 and 30, respectively. There are no specific criteria for organic content, but it is generally recommended that the organic content be kept to less than 5 percent by weight. There are no specific criteria available for petrographic examination. The test is used as an indicator for the presence of extraneous, potentially problematic materials. At present ASTM D4792 has been used for testing steel slag aggregate. Expansion limits of 0.5 percent have been established by	Atterberg Limit, ASTM D4318, AASHTO T90 Sand Equivalent, ASTM D2419, AASHTO T176 Petrographic Examination, ASTM C295 Moisture, Ash and Organic Matter of Peat Materials, ASTM D2974 Potential Expansion of Aggregates from Hydration Reactions, ASTM D4792

Table 4-6. Stage 2 laboratory testing recommendations for aggregate substitutes in granular base (continued).

Engineering Property	Comment	Criteria	Test Method
	new material with suspected expansive properties is used in a granular base application.	various States for use of steel slag aggregate in granular base or subbase applications.	

Table 4-7. Stage 2 laboratory testing recommendations for substitute embankment or fill materials.

Engineering Property	Comment	Criteria	Test Method
Corrosion Resistance	Some materials can contain high salt contents or can alter the pH of the soils and induce corrosion problems if contacted with metal or concrete structures. Each source of material should be evaluated for corrosivity. Two ASTM test methods are available for evaluating potential corrosivity. They include ASTM G51 and G57.	There are no ASTM or AASHTO specification limits for pH or electrical resistivity of embankment or fill materials.	Corrosion Potential-pH, ASTM G51 Soil Resistivity by Wenner Electrode, ASTM G57
Permeability	Permeability or hydraulic conductivity testing is an important parameter when adequate drainage from the embankment or fill material is warranted in the particular application. The specific test method selected in many cases will be dependent on the specifying agency.	There are no specific permeability requirements for embankment and fill materials. Where frost susceptibility is a concern, a permeability of greater than E-03 or between E-06 and E-08 cm/sec is typically desirable.	Constant Head Permeability, ASTM D2434, AASHTO T215 Flexible Wall Triaxial Permeability Test, ASTM D5084
Compressibility	The compressibility (or consolidation) of a fill material is related to its shear strength, degree of compaction, void ratio, permeability, and degree of saturation. It is therefore a function of the materials used for fill or embankment construction, and must be established for fill or embankment design. Two ASTM test methods are available to quantity consolidation. They include ASTM D2435 and ASTM D4186.	There are no specific requirements or limits in ASTM or AASHTO.	Consolidation Properties of Soils, ASTM D2435, AASHTO T216 Controlled Strain Test, ASTM D4186
Bearing Capacity	Determination of bearing capacity is important to assess whether the embankment or fill material will be capable of supporting pavement loads that may be imposed on it without structural damage. The California Bearing Ratio Test (CBR) is typically used. It is a comparative measure of the support capability of the test material with that of a well-graded crushed stone.	Minimum California Bearing Ratio (CBR) values may be specified for selected embankment and fill applications. The higher the CBR or the subgrade material, generally the thinner the pavement structure, with a soaked CBR of at least 5, and preferably 10, percent or more desirable.	California Bearing Ratio, ASTM D1883, AASHTO T193

Table 4-7. Stage 2 laboratory testing recommendations for substitute embankment or fill materials (continued).

Engineering Property	Comment	Criteria	Test Method
Specific Gravity/Unit Weight	The bulk relative density or unit weight of fill or embankment materials determines the total load transmitted to the underlying soil. The data are necessary to determine the potential consolidation of the underlying subsoil due to the embankment loading and are also used in determining the safety factors for side slope stability analysis. Substitute materials with low compacted density offer the advantage of transmitting less load to the supporting surface when compared with most conventional materials.	There are no ASTM or AASHTO specification limits for embankment fill materials, although the use of lightweight materials will generally be advantageous.	Unit Weight and Voids, ASTM C29 Specific Gravity of Soils, ASTM D854, AASHTO T100
Deleterious Materials	Petrographic examination (ASTM C295) can be used to visually identify the presence of excess debris or organic matter that could compromise the long-term quality of the fill material. Separate organic content tests are also available (ASTM D2974) to quantify organic matter. When a substitute material is introduced as an embankment material in a confined area where expansion might be a problem, then an evaluation of the potential for expansion is needed. ASTM D4792 is a volumetric stability test that has been used to evaluate the volumetric instability of steel slag aggregates.	The ASTM C295 petrographic examination test method has no formal specification requirements and is used as an indicator to screen for problematic constituents. An organic content value (ASTM D2974) of less than 5 percent has been recommended by some jurisdictions. ASTM D4792 has no specific criteria for use in an embankment of fill application. Expansion limits of 0.5 percent have been used by some jurisdictions in evaluating its potential for volumetric instability in granular base applications.	Petrographic Examination of Aggregates for Concrete, ASTM C295 Moisture, Ash and Organic Matter of Peat Materials, ASTM D2974 Potential Expansion of Aggregate from Hydration Reactions, ASTM D4792

Table 4-7. Stage 2 laboratory testing recommendations for substitute embankment or fill materials (continued).

Engineering Property	Comment	Criteria	Test Method
Gradation	Mixtures of granular and fine-grained soils are most suitable for embankment or fill construction.	There are no ASTM or AASHTO specification limits for embankment fill materials. A wide range of materials may be considered for this purpose. Some jurisdictions limit the quantity of percent passing the 0.075-mm (No. 200 sieve) size.	Sieve Analysis, ASTM C136 Hydrometer Analysis, ASTM D422
Moisture Density Characteristics	Most specifications for embankment or fill construction require the compacted fill material to achieve a target in-place density. The modified Proctor test is usually specified where the embankment/fill must have higher shear strength and hence must be more dense.	The moisture-density relationship must be established to determine if the embankment/fill material is compactible (moisture content within ±2 percent of the optimum Proctor moisture content). This information is also used for fill/embankment construction as the reference density for compaction (typically specified to be at least 95 percent of the Standard Proctor maximum dry density).	Standard Proctor, ASTM D698, AASHTO T99 Modified Proctor, ASTM D1557, AASHTO T180
Shear Strength	Shear strength characteristics are indicative of the ability of the material to support loads imposed under given drainage conditions. The data are normally used to determine slope stability when this is required.	The strength properties are a function of the materials used for fill or embankment construction, and must be established for fill or embankment design. There are no specific requirements or limits in ASTM or AASHTO.	Unconfined Undrained Triaxial, ASTM D2850 Consolidated Drained Direct Shear, ASTM D3080 Consolidated Drained Triaxial, ASTM D4767

Table 4-8. Stage 2 laboratory testing recommendations for aggregate or filler substitutes in stabilized base.

Engineering Property	Comment	Criteria	Test Method
Deleterious Materials	The presence of deleterious materials such as plastic fines, organic matter, or extraneous debris that might be present in recycled materials could reduce the expected performance of a stabilized base. The Atterberg limit test is the most widely used test for characterizing plasticity. Other tests (e.g., sand equivalent test) might be used if required by the specifying jurisdiction. Petrographic examination could assist in identifying the presence of extraneous debris. Volumetrically unstable materials could be a problem in a stabilized base application. The ASTM D4792 test method is a procedure that has been used with steel slag aggregate, a volumetrically unstable material.	There are no ASTM or AASHTO specification requirements for ASTM D2419. ASTM D2940 specifies that the fraction of material passing the 425-µm sieve in conventional granular base and subbase should have sand equivalent values of not lower than 35 and 30, respectively. These limits are also considered to be appropriate for stabilized base and subbase applications. ASTM D1241 specifies that the fraction of material passing the 425-µm sieve in fine aggregates for stabilized base and subbase should have a liquid limit less than or equal to 25 and a plasticity index not greater than 6. There are no specific criteria available for petrographic examination. The test is used as an indicator for the presence of extraneous, potentially problematic materials. ASTM D4792 has no specific criteria for use in a stabilized base application. It has been used to evaluate steel slag expansion problems, where a limit of 1 to 2 percent has been used by some jurisdictions for its use in asphalt concrete and 0.5 percent for its use in granular base. Any expansion beyond this latter amount could suggest potential volumetric instability problems.	Atterberg Limit, ASTM D4328, AASHTO T90 Sand Equivalent, ASTM D2419, AASHTO T176 Petrographic Examination, ASTM C295 Potential Expansion of Aggregates from Hydration Reactions, ASTM D4792

Table 4-8. Stage 2 laboratory testing recommendations for aggregate or filler substitutes in stabilized base (continued).

Engineering Property	Comment	Criteria	Test Method
Durability	It is desirable that recycled materials that are used in stabilized bases be sound and durable. Magnesium and sulfate soundness tests are used to evaluate the durability of aggregate-like material during wetting and drying, while freeze-thaw tests are typically used to evaluate the durability during freezing and thawing.	There are no specific ASTM or AASHTO requirements for magnesium sulfate soundness or sodium sulfate loss. Some agencies have adopted a maximum loss of 20 percent in the magnesium sulfate soundness test, and 15 percent for sodium sulfate soundness. There are no ASTM or AASHTO specification requirements for freeze-thaw soundness. A loss of less than 6 percent would typically be considered adequate.	Magnesium or Sulfate Soundness, ASTM C88, AASHTO T104 Freeze-Thaw Soundness, AASHTO T103
Gradation	A wide range of aggregate gradations may be considered for use in stabilized base mixes, provided mixture design data for strength and durability can be furnished. In many instances the lack of optimum particle sizing in a stabilized base can be overcome by the addition of additional binding agents (e.g., cement). To maximize mix density and minimize void spaces, stabilized mixes are typically designed with fine aggregate (minus 4.75 mm) comprising approximately 55 percent of the mix.	Specific gradation limits will vary from agency to agency, and for the intended use (base, subbase, etc.). Grading limits are generally based on ASTM D2940 or AASHTO M147.	Sieve Analysis, ASTM C136, AASHTO T27

Table 4-8. Stage 2 laboratory testing recommendations for aggregate or filler substitutes in stabilized base (continued).

Engineering Property	Comment	Criteria	Test Method
Particle Shape and Texture	Particle shape and texture tests are important to establish whether the interlocking particles can be expected to produce a stable mix. Cubical and angular particles can enhance the performance of a mix, but mixture design can be modified to compensate for the presence of excessive amounts of flat and elongated particles, if desired. ASTM D4791 is recommended for coarse aggregate testing, while AASHTO TP33 is recommended for fine aggregate testing.	There are no ASTM or AASHTO specification requirements for flat and elongated particles. It is recommended by the National Stone Association that the maximum percentage of flat and elongated particles in coarse aggregate should not exceed about 20 percent for strength considerations. The ASTM TP33 uncompacted voids content test applies to fine aggregate only. While there are no formal requirements to this test, the data may be a useful indicator of the influence of fine aggregate shape on density and strength.	Flat and Elongated Particles, ASTM D4791 Uncompacted Voids Content, AASHTO TP33

Table 4-8. Stage 2 laboratory testing recommendations for aggregate or filler substitutes in stabilized base (continued).

Engineering Property	Comment	Criteria	Test Method
Particle Strength	It is desirable that substitute materials in stabilized base mixtures possess sufficient particle strength to resist degradation and breakdown during construction and under repeated traffic loads. Particle strength can be assessed by LA abrasion testing, which is presently the standard test used by most specifying agencies in the United States. The MicroDeval test is a test method developed in France during the 1960s and has been adopted by the Ministry of Transportation in Ontario (MTO). It is under evaluation in the United States as an alternative method to the LA Abrasion test. MicroDeval testing may be more suitable than LA abrasion and can be used for evaluating fine aggregate (sand-size) particle strength down to 75 microns in size. It may be possible to compensate for particles that do not exhibit adequate strength by adjusting the binder content (e.g., cement) of stabilized base mixes.	ASTM D1241 specifies a maximum LA abrasion loss of 50 percent for conventional aggregates used in subbase, base and surface courses for materials with average specific gravity, absorption, and gradation characteristics. The Ontario Ministry of Transportation in Canada specifies a maximum loss of 25 percent for the coarse portion of granular base material, and 30 percent for granular subbase. The same limits are considered to be appropriate for aggregates used in stabilized base/subbase applications. The Ontario Ministry of Transportation specifies a maximum loss of 30 percent for the fine portion of granular base material, and 35 percent for granular subbase. The same limits are considered to be appropriate for aggregates used in stabilized base/subbase applications.	LA Abrasion, Small Size Aggregate, ASTM C131, AASHTO T96 Resistance of Coarse Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 618 Resistance of Fine Aggregate to Abrasion in the MicroDeval Apparatus, MTO LS 619
Unit Weight	The unit weight of a recycled material will be an indication of the compacted density of the mix.	There are no ASTM or AASHTO specification limits for unit weight. The unit weight and voids in aggregate data may be used to determine mixture proportions for stabilized base applications.	Unit Weight and Voids in Aggregate, ASTM C29/C29M, AASHTO T19

Table 4-9. Stage 2 laboratory testing recommendations for performance in stabilized base.

Engineering Property	Comment	Criteria	Test Method
Dimensional Stability	In applications where the stabilized base/subbase may be confined, such as in pavement structures or around buried services or against walls, the stabilized material must be volumetrically stable, and not expand, which exerts pressures on adjacent structures and/or causes heaving.	There are no ASTM or AASHTO specification requirements for stabilized base dimensional stability.	One-Dimensional Expansion, Shrinkage and Uplift Pressure, ASTM D3877
Durability	A well-compacted stabilized base mixture should be capable of resisting the deteriorating effects of freezing and thawing and wetting and drying cycles. ASTM D560 can be used to assess the durability of the stabilized base/subbase and/or stabilized subgrade in cycles of freezing and thawing and is only needed in cold climates where the pavement will be subjected to freezing. ASTM D559 can be used to assess wetting and drying cycles. Both of these test methods are better suited for stabilized bases using calcium-based binders than bituminous-based binders.	There are no ASTM or AASHTO specification requirements for freeze-thaw or wetting and drying cycle durability for stabilized bases.	Freeze-Thaw Test of Compacted Soil-Cement Mixtures, ASTM D560 Wetting and Drying Compacted Soil-Cement Mixtures, ASTM D559

Table 4-9. Stage 2 laboratory testing recommendations for performance in stabilized base (continued).

Engineering Property	Comment	Criteria	Test Method
Moisture-Density Relationship	To develop the design strength of a cement (calcium based) stabilized base mixture, the material should be well-compacted and as close as possible to its optimum moisture content when tested and placed. Moisture density is needed to determine the optimum moisture content and maximum density of the mix.	The moisture-density relationship must be established to determine if the stabilized base/subbase material is compactible (moisture content within 2 percent of the optimum Proctor moisture content). This information is also used for construction as the reference density for compaction (typically specified to be at least 98 to 100 percent of the Standard Proctor maximum dry density). The modified Proctor test is usually specified where the stabilized base/subbase must be more dense.	Standard Proctor, ASTM D698, AASHTO T99 Modified Proctor, ASTM D1557, AASHTO T180 Moisture-Density Relations of Soil-Cement Mixtures, ASTM D558

Table 4-9. Stage 2 laboratory testing recommendations for performance in stabilized base (continued).

Engineering Property	Comment	Criteria	Test Method
Strength or Stability	Testing approaches used to characterize the property of strength or stability (whichever is to be evaluated) in stabilized bases will be dependent on the design goals and binding reagents used in the stabilized base mix. For calcium-based binders such as lime or portland cement, compressive strength tests or bearing tests will in most cases be suitable measures for characterizing stabilized base strengths. For bituminous-based binders such as asphalt cement or asphalt emulsions, bituminous stability tests typically undertaken as part of asphaltic stabilized base design methods can be employed.	There are no ASTM or AASHTO specification requirements for strength or stability in stabilized base applications. The recommended procedure is to compare the compactive effect of introducing recycled materials into stabilized bases with that of control mixes using conventional materials.	For calcium-based binders recommended test methods include: Bearing Ratio of Laboratory Compacted Soil-Cement Mixtures, ASTM D3668 Compressive Strength of Molded Soil-Cement Cylinders, ASTM D1633 Compressive Strength of Cylindrical Specimens, ASTM C39, AASHTO T22 For bituminous-based binders recommended test methods include: Compressive Strength of Bituminous Based Mixtures, ASTM D1074 Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus, ASTM D1559, AASHTO T245 Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem Apparatus, ASTM D1560, AASHTO T247

Table 4-10. Stage 2 laboratory testing recommendations for aggregate substitute in flowable fill.

Engineering Property	Comment	Criteria	Test Method
Deleterious Materials	A visual or petrographic examination should be made of the substitute material source to ensure that the material does not contain excess debris that could compromise the quality of the flowable fill matrix. Additional testing may be warranted if unknown extraneous materials are present.	There are no formal specification requirements for petrographic or visual examination of a material. The results can be used as an indicator to screen for problematic constituents.	Petrographic Examination of Aggregates for Concrete, ASTM C295
Unit Weight	The unit weight of fine aggregate introduced into a flowable fill blend will determine to a great extent the unit weight of the mix. Low to moderate weight materials will facilitate flowability and minimize partial segregation in the mix.	There are no ASTM or AASHTO specification limits for unit weight and voids. The unit weight and voids in aggregate data are used to determine concrete mixture proportions in accordance with the American Concrete Institute (ACI) volumetric concrete mix design procedure.	Unit Weight and Voids in Aggregate, ASTM C29
Gradation	It is necessary to determine the gradation of flowable fill blend to assess the strength and flow characteristics of the mix. Well-graded cementitious mixes may yield strengths that exceed desired levels. The design of a harsh mix, which is a stiff, low flow mix with a preponderance of granular material, should also be avoided. Blending of highly angular materials with a more rounded material (natural sand) may be needed to enhance the flowability of the mix.	There are no ASTM or AASHTO specification limits for use of aggregates in flowable fill applications. Many jurisdictions specify that the gradation requirements of sand used in flowable fill comply with the ASTM C33 specification for fine concrete aggregates.	Sieve Analysis, ASTM C136, AASHTO T27

Table 4-10. Stage 2 laboratory testing recommendations for aggregate substitute in flowable fill (continued).

Engineering Property	Comment	Criteria	Test Method
Fineness	This test method would only be applicable if the new aggregate or filler being introduced is expected to exhibit pozzolanic properties.	Specification requirements vary with the type of pozzolan and are provided in ASTM C618. Although many jurisdictions utilize these specifications (most notably for coal fly ash use in portland cement concrete), the actual fineness of the recycled material is not as important in flowable fill mixes as consistent values. A consistent fineness is a good indication of a quality material.	Testing Fly Ash & Natural Pozzolans in Portland Cement Concrete, ASTM C311

Table 4-11. Stage 2 laboratory testing recommendations for performance in flowable fill.

Performance Test	Comment	Criteria	Test Method
Hardening Time	The hardening time of flowable fill mixes is usually related to the cement quantity and type, and the presence and type of fine aggregate and fillers. The introduction of substitute materials could inhibit or slow the curing process and should be investigated.	There are no ASTM or AASHTO specification limits for setting time for flowable fill. The setting time requirements are a function of the intended use and specified, then designed, accordingly.	Setting Time by Penetration Resistance, ASTM C403
Strength Development	Compressive strength is an important performance test that is needed to ensure that the flowable fill product (after curing) will meet the strength commensurate with the intended use. The test method selected will generally depend on the specifying jurisdiction and the flowable fill mix design. ASTM C39 will normally be conducted when a cement stabilized mix has been prepared to develop strength with time. ASTM D2166 can be used where minimal or no cement is added to the blend. ASTM D4219 can be used for highly fluid grout-like mixes.	There are no ASTM or AASHTO compressive strength specification limits for flowable fill. The specific requirements will depend on the application and the specifying jurisdiction. Flowable fill mixes are usually designed on the basis of a minimum 24-hour strength and a 28-day maximum compressive strength, usually between 340 kPa (50 lb/in sq) and 1400 kPa (200 lb/in sq).	Unconfined Compressive Strength of Concrete Specimens, ASTM C39, AASHTO T22 Unconfined Compressive Strength of Cohesive Soil, ASTM D2166 Unconfined Compressive Strength of Chemical Grouted Soils, ASTM D4219
Shear Strength	Shear strength could be an important property, particularly if the flowable fill mix is formed above grade. The shear strength of a flowable fill is a combination of cohesion and internal friction and is related to the development of compressive strength. Two types of tests are available for measuring shear strength and include the triaxial test and the direct shear test.	There are no ASTM or AASHTO specification limits for shear strength for flowable fill. The shear strength requirements are a function of the intended use and specified, then designed, accordingly.	Triaxial Testing of Cohesive Soils, ASTM D2850 Direct Shear Test, ASTM D3080

Table 4-11. Stage 2 laboratory testing recommendations for performance in flowable fill (continued).

Performance Test	Comment	Criteria	Test Method
Bleeding and Shrinkage	Bleeding and shrinkage is usually associated with flowable fill mixes containing high water contents. Bleed water evaporation often results in shrinkage, which can result in water infiltration, freezing, and subsequent frost damage. Mixes should be checked for shrinkage when substitute materials are introduced.	Flowable fill mixtures are generally specified as nonshrinking, and as a result there should be no appreciable change in volume during setting. A maximum of 1 percent of the total height of the test specimen is generally considered tolerable.	Change in Height of Cylindrical Specimens, ASTM C827
Flowability	A feature of flowable fill is its ability to flow to fill cracks and voids. Flowability can be measured by one of several methods, including the slump and flow cone test. This test is appropriate for flowable fill mixtures comprised of both coarse and fine aggregates.	There are no ASTM or AASHTO specification limits for slump or flow. The normal desired slump range is 150 mm (6 in) to 250 mm (10 in). The normal desired flow time ranges from 30 to 60 seconds.	Slump, ASTM C143 Flow of Grout, ASTM C939
Bearing Strength	Bearing strength can sometimes be used as an indication of the support capability of flowable fill. Depending on the compressive strength of the flowable fill, the hardened material can have California Bearing Ratio (CBR) values that are normally in the range of 40 to 90 percent. Compressive strength is sometimes used as an alternate test to assess support capability in flowable fill.	There are no ASTM or AASHTO specification limits for bearing capacity or bearing ratios recorded in the California Bearing Ratio (CBR) in flowable fill. A CBR value of 100 provides a bearing capacity that is similar to a high-quality granular base material.	California Bearing Ratio, ASTM D1883
Corrosion Resistance	Any contact between flowable fill and metal pipes could result in corrosive reactions. Flowable fill will normally exhibit an alkaline pH. Depending on its additives, if the pH of the mix exhibits highly alkaline characteristics (pH ≥ 12) corrosion of metal pipes or pilings could be a problem. Electrical resistivity can be expected to increase over time with curing, also reducing corrosivity concerns.	There are no ASTM or AASHTO specification limits for pH or electrical resistivity of flowable fill.	Corrosion Testing (pH), ASTM G51 Electrical Resistivity Test, ASTM G57

Table 4-11. Stage 2 laboratory testing recommendations for performance in flowable fill (continued).

Performance Test	Comment	Criteria	Test Method
Unit Weight	The unit weight of the flowable fill mix can provide information on the expected soil burden, which could be important if poor subsurface soil conditions exist. It also is used to check the unit weight of the flowable fill per cubic meter and its actual yield (volume of flowable fill produced from a mixture of known quantities of the component materials) for comparison with that determined theoretically at the mix design stage.	There are no ASTM or AASHTO specification unit weight limits for flowable fill.	Unit Weight, Yield and Air Content of Concrete, ASTM C138

Table 4-12. Stage 2 laboratory testing recommendations for landscaping materials.

Engineering Property	Comment	Criteria	Test Method
Organic Matter	Organic content testing is one of several test methods that will typically be required to assess the quality of a biodegraded organic biosolid.	Composted biosolids generally fall within an organic content range of 40 to 60 percent.	Organic Content, ASTM D5268
Gradation	Sieve testing is necessary to evaluate particle size requirements.	Gradation limits will vary for landscaping materials from agency to agency depending on the type of landscaping material being used. Organic compost will typically require 100 percent passing a 19-mm (3/4-in) sieve. Wood chips, shredded bark, etc., can have varying requirements.	Sieve Analysis, ASTM C136, AASHTO T27
Water Retentivity	Retention of moisture is an important property if one of the objectives of the landscaping material is to support plant growth.	Water retentivity criteria will be dependent on the type of plant growth desired and the regional climate.	Capillary-Moisture Relationships, ASTM D2325 and D3152

INTRODUCTION

In a Stage 2 environmental, health, and safety laboratory evaluation, a laboratory testing program must be developed that will provide sufficient data to demonstrate that the proposed material is suitable for use in its intended application.

To undertake this Stage 2 evaluation it is recommended that (1) a laboratory environmental test plan be prepared to identify the methods and procedures to be used in evaluating the material and its proposed application, (2) suitable performance criteria be identified by the decision maker, and (3) the test data need to be statistically evaluated to determine if the established test criteria are met.

Figure 5-1 provides a flowchart highlighting the sequential steps in an environmental, health, and safety Stage 2 evaluation. Included in Figure 5-1 is reference to Tables 5-1 through 5-3, which present recommended environmental, health, and safety test methods for applications in which the recycled material is used as an aggregate substitute material in an unbound form (e.g., granular base), applications in which an aggregate substitute material is used in a bound form (e.g., concrete), and applications in which the recycled material is used as a landscaping material and contains a significant organic fraction (e.g., biosolids). Tables 5-1 through 5-3 contain three columns: (1) a comment column that provides a description of the purpose of the test and when the test should be used, (2) a criteria column that provides a description of available or suggested test criteria, and (3) a description and reference for potential test methods that could be used.

Inherent in the use of this flowchart is that laboratory testing requires assessment of the environmental performance of the proposed material as well as the environmental performance of the product. Finally, it is important to consider environmental performance in potential post-service life utilization scenarios. While these reuse scenarios cannot be precisely described, it is important to identify to the extent possible future environmental issues that may arise if the recycled material is reused.

LABORATORY ENVIRONMENTAL, HEALTH, AND SAFETY TEST PLAN

The environmental, health, and safety laboratory test plan should contain all appropriate test methods and procedures, including suitable reference materials to be used, test criteria, and statistical procedures to be used to compare the laboratory data with criteria or with the performance of the reference material.

Some recycled materials proposed for use in a given application may have unique properties that do not readily lend themselves to environmental testing as prescribed in the proposed test methods. For example, there are no standardized methods to evaluate particulate release or volatilization release for any application. In such cases, alternative methods may be

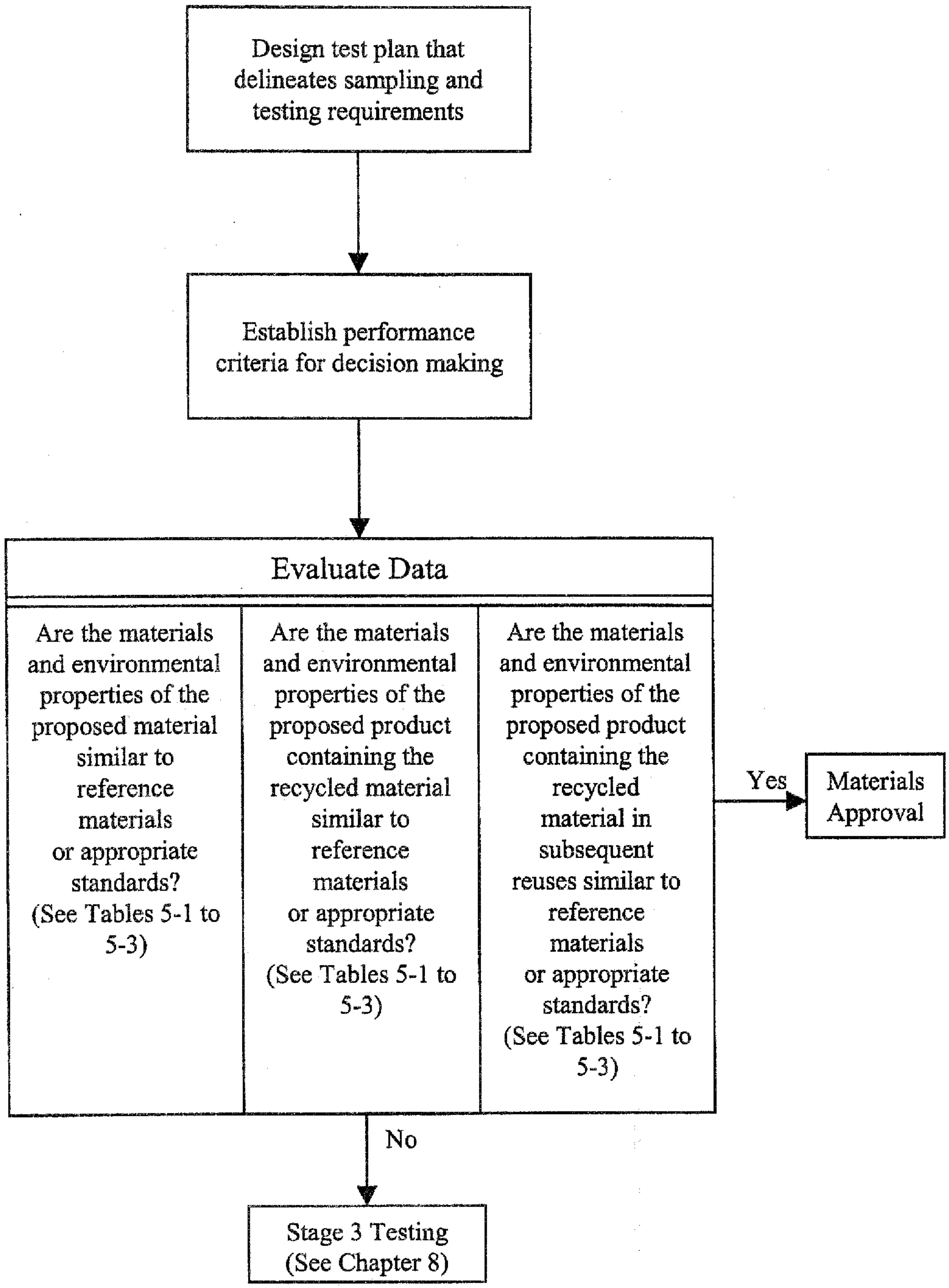

Figure 5-1. Environmental, health, and safety properties laboratory testing flowchart.

needed or field evaluations may be necessary. Tables 5-1 through 5-3 present some recommended test methods.

ESTABLISH ACCEPTABLE CRITERIA

During the development of the test plan, the decision maker will need to determine the criteria on which approval will be based. Two types of criteria are available for use in such an evaluation. The first includes existing environmental standards that address clean soil, groundwaters, surface waters, ambient air, and indoor or workplace air quality criteria. Most of these criteria have been established by Federal and State agencies. They are based on likely impacts to receptors resulting from ingestion, inhalation, or dermal exposure. By estimating the release of contaminants on the basis of laboratory tests and emission release scenarios anticipated during the design life of the application and during subsequent reuses, it is possible to estimate (typically using environmental models) whether these criteria will be exceeded. The second criterion involves a comparison of emissions from the recycled material to a control or reference material (e.g., conventional construction material) to assess the relative environmental properties of the recycled material versus that of the reference material.

Tables 5-1 through 5-3 provide a description of available criteria or recommendations on which the decision maker can make an evaluation. Chapter 10 provides a listing and description of available web sites (as of this writing) that can be used to access information on assessment methodologies and criteria that can be used in a Stage 2 evaluation.

When testing new materials in highway construction applications, the passing or failing of one environmental parameter may not warrant a rejection of the material, particularly if performance testing suggests that the final product will perform satisfactorily. There may be instances where the proposed material yields questionable leaching results for one inorganic constituent, but in the proposed application (e.g., asphalt pavement), the leaching behavior of the product performs in an acceptable manner. When a questionable situation arises, the decision maker can pursue Stage 3 field evaluations to resolve laboratory uncertainties.

EVALUATE LABORATORY DATA FOR POSSIBLE APPROVAL

As illustrated in Figure 5-1, data comparisons between the recycled material and reference materials, or between the recycled material and/or appropriate criteria, will be required to evaluate the suitability of the application. Such comparative analyses are best undertaken using standard statistical procedures. Examples of such statistical procedures are presented in Chapter 9.

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications.

Environmental Property	Comment	Criteria	Test Method
Regulatory Testing of Aggregate Substitute	U.S. EPA regulatory testing consists of material properties. They include ignitability, corrosivity, reactivity, and toxicity characteristics. Regulatory testing is used to determine if the material is hazardous or nonhazardous from a regulatory perspective.	The criteria for ignitability is defined by 40 CFR, Part 261.21. The criteria for corrosivity is defined by 40 CFR, Part 261.22. The criteria for reactivity is defined by 40 CFR, Part 261.23. The criteria for toxicity characteristics require leaching tests and are listed in 40 CFR, Part 261.24, Table-1. Leachate concentration limitations exist for eight inorganic compounds and numerous organic compounds.	The U.S. EPA does not list a standard test method for testing the ignitability of a solid, but provides the characteristics of an ignitable solid in 40 CFR, Part 261.21. The U.S. EPA lists standard test for corrosivity as Method 5.2 in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods" and National Association of Corrosion Engineers Standard TM-01-69. The U.S. EPA does not list a standard test method for testing the reactivity of a solid, but provides the characteristics of a reactive solid in 40 CFR, Part 261.23. The Toxicity Characteristics Leaching Procedure (TCLP) Test, SW-846 1311 is used to characterize toxicity characteristics. This method was originally developed to simulate leaching in a municipal solid waste landfill environment.

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Inorganic Composition of Aggregate Substitute	Inorganic composition provides information on the elemental composition of the aggregate substitute material (e.g., Al, As, Ba, Cd, Cu, Fe, Hg, Mg, Se, Zn). The main environmental concerns are excessive concentrations of trace metals. Inorganic composition determination should be made when the composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to be similar to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) clean soil guidelines, then the material may not need further testing and is acceptable from an environmental perspective. From a health and safety perspective, in some cases, materials with similar composition may have different leaching behaviors. If the materials are of widely different origin, the mineralogies may differ. Therefore, in addition to comparisons of inorganic composition between the proposed and reference materials, evaluations using leaching tests (such as total availability or pH-dependent methods) may be required. From a health and safety perspective, there may be potential issues relative to fugitive dust emissions during stockpiling, processing, and eventual recycling and, as a result, the inorganic composition of the fine fraction (and its potential relation to air-entrained particulate matter) may need to be compared with applicable OSHA standards for worker safety and exposure to air-entrained particulate matter limits.	Standard U.S. EPA methods to determine inorganic composition are normally undertaken by totally digesting the material and analyzing the digestate using atomic absorption spectrometry, atomic emission spectrometry or ion chromatography. When using total digestion techniques, care should be taken to (i) prevent loss of volatile elements like Hg and (ii) ensure that silicates in the recycled material are completely digested. See Standard Methods 3030 I and K for digestion, and Standard Methods 3111, 3112, 3113, 3114, 3120, 3125, and 4110 for digestate analysis of SW-846 3050B and 3051 for digestion and SW-846 6010B, 6020, 7000A for digestate analysis. Inorganic composition can also be determined using solid state methods such as x-ray fluorescence analysis (XRF) or neutron activation analysis (NAA). Solid state methods are generally easier (no digestion, reasonably good detection limits), and less costly, but less routinely available.

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Organic Composition of Aggregate Substitute	Organic composition provides information that can indicate if the proposed recycled material is contaminated with or contains compounds of concern (e.g., volatile organics, pesticides, semi-volatile organics). Organic composition determination should be made when the composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to be similar to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soil" guidelines, then the material may not need further testing and is acceptable from an environmental perspective. From a health and safety perspective, since the material will be used in an unbound application, there may be potential issues relative to fugitive dust and volatile emissions during stockpiling, processing, and eventual recycling and, as a result, the organic composition of the fine fraction (and its potential relation to air-entrained particulate matter) may need to be compared with applicable OSHA standards for worker safety and exposure to air-entrained particulate matter limits.	Many standard U.S. EPA methodologies exist for the determination of the organic composition of a material. Organics Composition Using Extraction, Clean-Up and Detection of Organic Compounds Using Gas Chromatographic Methods for Total Petroleum Hydrocarbons (SW-846 8015) and Gas Chromatographic/Mass Spectroscopic Methods for Volatile Compounds (SW-8260B), Semivolatile Compounds (SW-846 8270C), Polyaromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) (SW-846 8275A), and Polychlorinated Dibenzodioxins/Dibenzofurans (PCDDs/PCDFs) (SW-846 8280A or 8290). A more comprehensive listing of organic test methods can be found in SW-846.
Particle Size of Aggregate Substitute	Particle size analysis is a measure of the size distribution of the material. Particle size analysis should be undertaken if fugitive dust emissions are expected.	From a health and safety perspective, applicable standards for levels of fugitive dusts are listed in 29 CFR, Part 1910. If fugitive emissions are suspected, then the inorganic and organic composition of the material may need to be analyzed and the composition of the fine fraction compared with OSHA Standards listed in 29 CFR, Part 1910, Tables Z-1, Z-2, Z-3, and Z-4.	For particle size determination of 75 microns or greater, ASTM C136 or AASHTO T27 can be used to quantity particle sizes. For particle size determination of less than 75 microns, ASTM method D422 can be used.

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Mineralogical Composition of Aggregate Substitute	Mineralogical composition testing is useful to determine the inorganic crystalline phases of a material. Determination of inorganic crystalline structure should be performed when the mineralogical composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	There are no applicable environmental criteria. The presence of certain mineral phases [e.g., chrysotile (asbestos), quartz SiO_2] have health and safety implications. Mineralogical analyses can be used to identify and quantify such phases. Criteria can be found in 29 CFR, Part 1910.	Mineralogy using x-ray powder diffraction or other solid state spectroscopies. Besides x-ray diffraction, there are a number of additional spectroscopies that can be used to characterize the materials (e.g., x-ray, photoelectron spectroscopy, solid state nuclear magnetic resonance spectroscopy, vibrational spectroscopies, etc.).
Inorganic Leaching of Aggregate Substitute	Inorganic leaching can be used to determine the amount of soluble inorganic components that could be released from the proposed material. Testing of inorganic leaching should be done when high concentrations of inorganic constituents are present, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	Determination of inorganic leaching can be performed to analyze for (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to determine what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to solid ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1312 (SPLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987 (Shake Extraction of Solid Waste With Water), ASTM D4793, and the NEN 7343 Dutch Column Leaching Test.

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications (continued).

Environmental Property	Comment	Criteria	Test Method
			Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343).
Organic Leaching of Aggregate Substitute	Organic leaching can be used to determine the amount of soluble organic components in the aggregate substitute. Testing of organic leaching should be done when high concentrations of organic constituents are present, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	There are no standard methods for determination of organic leaching, but the leaching methods listed below can be used in conjunction with appropriate organic analysis methods to determine (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to tell what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to volume ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987, and ASTM D4793. Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343).

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications (continued).

Environmental Property	Comment	Criteria	Test Method
			The tests can be modified to analyze organics in the leachates using such methods as EPA 601, 8010, 602, 8020, 8015, 624, 8240, 8260, 524.2 (Volatile Compounds) or EPA 625, 8270 (Acid and Base-Neutral Extractables), EPA 608, 8080 (Pesticides, PCBs), or EPA 8100 (Total Petroleum Hydrocarbons).

Table 5-1. Stage 2 laboratory testing recommendations for aggregate substitutes in unbound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Acid-Base Behavior of Aggregate Substitute	Acid base behavior testing is an analytical approach that can be used to determine the leaching characteristics of the material in different pH environments. It can be determined by examining the pH of the material, pH-dependent leaching behavior, and acid neutralization capacity of the proposed material. Determination of acid-base behavior is typically undertaken to gain a better understanding of the leaching of the proposed material.	From an environmental perspective and from a health and safety perspective, there are no specific criteria for acid-base behavior of a material. The information gathered from the associated test methods can be used to assess environmental conditions of acidity or alkalinity that could result in excessive leaching.	pH is a basic measure of the acid or alkaline nature of a granular material and pH is the principal factor in controlling the leaching of virtually all inorganics and some organics (e.g., acid or base neutral extractables like phenols) in recycled materials. Determination of pH can be made using SW-846 9045C. pH-dependent leaching is used to assess equilibrium leaching as a function of pH. It is useful to understand whether constituents will leach in acidic or basic conditions or exhibit pH-dependent leaching. The Dutch pH-Dependent Leach Test (NEN 7343) or an equivalent method can be used. Acid Neutralization Capacity (ANC) is the measure of the buffer capacity or ability to resist pH change. An ANC test method is available in ASTM C400; however, the method is not an ideal test and is really only applicable to very alkaline materials.

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications.

Environmental Property	Comment	Criteria	Test Method
Regulatory Testing of Aggregate Substitute	U. S. EPA regulatory testing consists of a series of material properties. They include ignitability, corrosivity, reactivity, and toxicity characteristics. Regulatory testing is used to determine if the material is hazardous or nonhazardous from a regulatory perspective.	The criteria for ignitability is defined by 40 CFR, Part 261.21. The criteria for corrosivity is defined by 40 CFR, Part 261.22. The criteria for reactivity is defined by 40 CFR, Part 261.23. The criteria for toxicity characteristics require leaching tests and are listed in 40 CFR, Part 261.24, Table-1. Leachate concentration limitations exist for eight inorganic compounds and numerous organic compounds.	The U.S. EPA does not list a standard test method for testing the ignitability of a solid, but provides the characteristics of an ignitable solid in 40 CFR, Part 261.21. The U.S. EPA lists standard test for corrosivity as Method 5.2 in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods" and National Association of Corrosion Engineers Standard TM-01-69. The U. S. EPA does not list a standard test method for testing the reactivity of a solid, but provides the characteristics of a reactive solid in 40 CFR, Part 261.23. The Toxicity Characteristics Leaching Procedure (TCLP) Test, SW-846 1311 is used to characterize toxicity characteristics. This method was originally developed to simulate leaching in a municipal solid waste landfill environment.

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Inorganic Composition of Aggregate Substitute	Inorganic composition provides information on the elemental composition of the aggregate substitute material (e.g., Al, As, Ba, Cd, Cu, Fe, Hg, Mg, Se, Zn). The main environmental concerns are excessive concentrations of trace metals. Inorganic composition determination should be made when the composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to be similar to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) clean soil guidelines, then the material may not need further testing and is acceptable from an environmental perspective. From a health and safety perspective, in some cases, materials with similar composition may have different leaching behaviors. If the materials are of widely different origin, the mineralogies may differ. Therefore, in addition to comparisons of inorganic composition between the proposed and reference materials, evaluations using leaching tests (such as total availability or pH-dependent methods) may be required. From a health and safety perspective, there may be potential issues relative to fugitive dust emissions during stockpiling, processing, and eventual recycling and, as a result, the inorganic composition of the fine fraction (and its potential relation to air-entrained particulate matter) may need to be compared with applicable OSHA standards for worker safety and exposure to air-entrained particulate matter limits.	Standard U.S. EPA methods to determine inorganic composition are normally undertaken by totally digesting the material and analyzing the digestate using atomic absorption spectrometry, atomic emission spectrometry, or ion chromatography. When using total digestion techniques, care should be taken to (i) prevent loss of volatile elements like Hg and (ii) ensure that silicates in the recycled material are completely digested. See Standard Methods 3030 I and K for digestion, and Standard Methods 3111, 3112, 3113, 3114, 3120, 3125, and 4110 for digestate analysis of SW-846 3050B and 3051 for digestion and SW-846 6010B, 6020, 7000A for digestate analysis. Inorganic composition can also be determined using solid state methods such as x-ray fluorescence analysis (XRF) or neutron activation analysis (NAA). Solid state methods are generally easier (no digestion, reasonably good detection limits), and less costly, but less routinely available.

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Organic Composition of Aggregate Substitute	Organic composition provides information that can indicate if the proposed recycled material is contaminated with or contains compounds of concern (e.g., volatile organics, pesticides, semi-volatile organics). Organic composition determination should be made when the composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to be similar to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soil" guidelines, then the material may not need further testing and is acceptable from an environmental perspective. From a health and safety perspective, since the material will be used in an unbound application, there may be potential issues relative to fugitive dust and volatile emissions during stockpiling, processing, and eventual recycling and, as a result, the organic composition of the fine fraction (and its potential relation to air-entrained particulate matter) may need to be compared with applicable OSHA standards for worker safety and exposure to air-entrained particulate matter limits.	Many standard U.S. EPA methodologies exist for the determination of the organic composition of a material. Organics Composition Using Extraction, Clean-Up and Detection of Organic Compounds Using Gas Chromatographic Methods for Total Petroleum Hydrocarbons (SW-846 8015) and Gas Chromatographic/Mass Spectroscopic Methods for Volatile Compounds (SW-8260B), Semivolatile Compounds (SW-846 8270C), Polyaromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) (SW-846 8275A), and Polychlorinated Dibenzodioxins/Dibenzofurans (PCDDs/PCDFs) (SW-846 8280A or 8290). A more comprehensive listing of organic test methods can be found in SW-846.
Particle Size of Aggregate Substitute	Particle size analysis is a measure of the size distribution of the material. Particle size analysis should be undertaken if fugitive dust emissions are expected.	From a health and safety perspective, applicable standards for levels of fugitive dusts are listed in 29 CFR, Part 1910. If fugitive emissions are suspected, then the inorganic and organic composition of the material may need to be analyzed and the composition of the fine fraction compared with OSHA Standards listed in 29 CFR, Part 1910, Tables Z-1, Z-2, Z-3, and Z-4.	For particle size determination of 75 microns or greater, ASTM C136 or AASHTO T27 can be used to quantity particle sizes. For particle size determination of less than 75 microns, ASTM D422 can be used.

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Mineralogical Composition of Aggregate Substitute	Mineralogical composition testing is useful to determine the inorganic crystalline phases of a material. Determination of inorganic crystalline structure should be performed when the mineralogical composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	There are no applicable environmental criteria. The presence of certain mineral phases [e.g., chrysotile (asbestos), quartz SiO_2] have health and safety implications. Mineralogical analyses can be used to identify and quantify such phases. Criteria can be found in 29 CFR, Part 1910.	Mineralogy using x-ray powder diffraction or other solid state spectroscopies. Besides x-ray diffraction, there are a number of additional spectroscopies that can be used to characterize the materials (e.g., x-ray, photoelectron spectroscopy, solid state nuclear magnetic resonance spectroscopy, vibrational spectroscopies, etc.).
Inorganic Leaching of Aggregate Substitute	Inorganic leaching can be used to determine the amount of soluble inorganic components that could be released from the proposed material. Testing of inorganic leaching should be done when high concentrations of inorganic constituents are present, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	Determination of inorganic leaching can be performed to analyze for (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to determine what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to solid ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1312 (SPLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987 (Shake Extraction of Solid Waste with Water), ASTM D4793, and the NEN 7343 Dutch Column Leaching Test.

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
			Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343).
Organic Leaching of Aggregate Substitute	Organic leaching can be used to determine the amount of soluble organic components in the aggregate substitute. Testing of organic leaching should be done when high concentrations of organic constituents are present, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	There are no standard methods for determination of organic leaching, but the leaching methods listed below can be used in conjunction with appropriate organic analysis methods to determine (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to tell what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to volume ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987, and ASTM D4793. Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343).

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
			The tests can be modified to analyze organics in the leachates using such methods as EPA 601, 8010, 602, 8020, 8015, 624, 8240, 8260, 524.2 (Volatile Compounds) or EPA 625, 8270 (Acid and Base-Neutral Extractables), EPA 608, 8080 (Pesticides, PCBs), or EPA 8100 (Total Petroleum Hydrocarbons).
Acid-Base Behavior of Aggregate Substitute	Acid base behavior testing is an analytical approach that can be used to determine the leaching characteristics of the material in different pH environments. It can be determined by examining the pH of the material, pH-dependent leaching behavior, and acid neutralization capacity of the proposed material. Determination of acid-base behavior is typically undertaken to gain a better understanding of the leaching of the proposed material.	From an environmental perspective and from a health and safety perspective, there are no specific criteria for acid-base behavior of a material. The information gathered from the associated test methods can be used to assess environmental conditions of acidity or alkalinity that could result in excessive leaching.	pH is a basic measure of the acid or alkaline nature of a granular material and pH is the principal factor in controlling the leaching of virtually all inorganics and some organics (e.g., acid or base neutral extractables like phenols) in recycled materials. Determination of pH can be made using SW-846 9045C. pH-dependent leaching is used to assess equilibrium leaching as a function of pH. It is useful to understand whether constituents will leach in acidic or basic conditions or exhibit pH-dependent leaching. The Dutch pH-Dependent Leach Test (NEN 7343) or an equivalent method can be used. Acid Neutralization Capacity (ANC) is the measure of the buffer capacity or ability to resist pH change. An ANC test method is available in ASTM C400; however, the method is not an ideal test and is really only applicable to very alkaline materials.

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Product Inorganic Leaching	Product inorganic leaching can be used to determine the amount of soluble inorganic components that could be released from the product. Testing of inorganic leaching should be undertaken when high concentrations of inorganic constituents are suspected, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	Determination of inorganic leaching can be performed to analyze for (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to determine what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to volume ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987, and ASTM D4793. Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343).

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
Product Organic Leaching	Product organic leaching can be used to determine the amount of soluble organic components that could be released from the product. Testing of organic leaching should be undertaken when high concentrations of organic constituents are suspected, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	There are no standard methods for determination of organic leaching, but the leaching methods listed below can be used in conjunction with appropriate organic analysis methods to determine (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to tell what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to volume ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987, and ASTM D4793. Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343). The tests can be modified to analyze organics in the leachates using such methods as EPA 601, 8010, 602, 8020, 8015, 624, 8240, 8260, 524.2 (Volatile Compounds) or EPA 625, 8270 (Acid and Base-Neutral Extractables), EPA

Table 5-2. Stage 2 laboratory testing recommendations for aggregate substitutes in bound applications (continued).

Environmental Property	Comment	Criteria	Test Method
			608, 8080 (Pesticides, PCBs), or EPA 8100 (Total Petroleum Hydrocarbons).
Product Abrasion	Product abrasion from a monolithic product can be used to quantify the potential particulate erosion from the product resulting from mechanical stress or weathering. This method would be used if it was expected that material loss was possible, and if the material loss could potentially result in environmental degradation (e.g., soil contamination, water contamination, or air pollution).	From an environmental perspective there are no specific criteria. If the proposed material is similar to referenced product materials, then product abrasion should not be a concern. If elevated organic or inorganic contaminants are present, the potential impacts to soils, water, and air will need to be evaluated, based on the rate of particulate abrasion and compared with soil quality, water quality, and air quality guidelines. There are no applicable health and safety criteria.	There are no laboratory methods to assess abrasion. If product abrasion is deemed to be problematic, then a simulated abrasion or a field test will be necessary to measure the effects of abrasion on the product.
Product – Volatile Emissions	This method ideally would look at the rate of loss of volatile components from the product. If original material contains volatile components and if the manufacturing of the material into a product could result in the release of volatile emissions, then such testing may be necessary.	There are no environmental criteria. From a health and safety perspective, potential emission rates could be determined with this method, modeled, and compared with appropriate OSHA standards.	There are no standard laboratory methods to estimate volatilization from unbound products. Laboratory methods can be developed that use glove bags and gas analysis methods.

Table 5-3. Stage 2 laboratory testing recommendations for landscaping materials.

Environmental Property	Comment	Criteria	Test Method
Regulatory Testing of Landscaping Material	U.S. EPA regulatory testing consists of a series of material properties. They include ignitability, corrosivity, reactivity, and toxicity characteristics. Regulatory testing is used to determine if the material is hazardous or nonhazardous from a regulatory perspective.	The criteria for ignitability is defined by 40 CFR, Part 261.21. The criteria for corrosivity is defined by 40 CFR, Part 261.22. The criteria for reactivity is defined by 40 CFR, Part 261.23. The criteria for toxicity characteristics require leaching tests and are listed in 40 CFR, Part 261.24. Leachate concentration limitations exist for eight inorganic compounds and numerous organic compounds.	The U.S. EPA does not list a standard test method for testing the ignitability of a solid, but provides the characteristics of an ignitable solid in 40 CFR, Part 261.21. The U.S. EPA lists standard test for corrosivity as Method 5.2 in "Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods" and National Association of Corrosion Engineers Standard TM-01-69. The U.S. EPA does not list a standard test method for testing the reactivity of a solid, but provides the characteristics of a reactive solid in 40 CFR, Part 261.23. The Toxicity Characteristics Leaching Procedure (TCLP) Test, SW-846 1311 is used to characterize toxicity characteristics. This method was originally developed to simulate leaching in a municipal solid waste landfill environment.

Table 5-3. Stage 2 laboratory testing recommendations for landscaping materials (continued).

Environmental Property	Comment	Criteria	Test Method
Inorganic Composition of Landscaping Material	Inorganic composition provides information on the elemental composition of the aggregate substitute material (e.g., Al, As, Ba, Cd, Cu, Fe, Hg, Mg, Se, Zn). The main environmental concerns are excessive concentrations of trace metals. Inorganic composition determination should be made when the composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	From an environmental perspective, U.S. EPA 503 regulations regulate the levels of contaminants that may be present in biosolids applied to the land. These criteria may be used as guidance criteria for materials other than biosolids. Alternatively, if the proposed material can be shown to be similar to reference materials such as (i) accepted landscaping materials or native materials (soils, crushed rock) or (ii) "clean soil" guidelines, then the material may not need further testing and should be acceptable. From a health and safety perspective, there may be potential issues relative to fugitive dust emissions during stockpiling, processing, and eventual recycling and, as a result, the inorganic composition of the fine fraction (and its potential relation to air-entrained particulate matter) may need to be compared with applicable OSHA standards for worker safety and exposure to air-entrained particulate matter limits.	Standard U.S. EPA methods to determine inorganic composition are normally undertaken by totally digesting the material and analyzing the digestate using atomic absorption spectrometry, atomic emission spectrometry, or ion chromatography. When using total digestion techniques, care should be taken to (i) prevent loss of volatile elements like Hg and (ii) ensure that silicates in the recycled material are completely digested. See Standard Methods 3030 I and K for digestion, and Standard Methods 3111, 3112, 3113, 3114, 3120, 3125, and 4110 for digestate analysis of SW-846 3050B and 3051 for digestion and SW-846 6010B, 6020, 7000A for digestate analysis. Inorganic composition can also be determined using solid state methods such as x-ray fluorescence analysis (XRF) or neutron activation analysis (NAA). Solid state methods are generally easier (no digestion, reasonably good detection limits), and less costly, but less routinely available.

Table 5-3. Stage 2 laboratory testing recommendations for landscaping materials (continued).

Environmental Property	Comment	Criteria	Test Method
Organic Composition of Landscaping Material	Organic composition provides information that can indicate if the proposed recycled material is contaminated with or contains compounds of concern (e.g., volatile organics, pesticides, semi-volatile organics). Organic composition determination should be made when the composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	From an environmental perspective, U.S. EPA 503 regulations regulate the levels of contaminants that may be present in biosolids applied to the land. These criteria may be used as guidance criteria for materials other than biosolids. Alternatively, if the proposed material can be shown to be similar to reference materials such as (i) accepted landscaping materials or native materials (soils, crushed rock) or (ii) "clean soil" guidelines, then the material may not need further testing and should be acceptable. From a health and safety perspective, since the material will be used in an unbound application, there may be potential issues relative to fugitive dust and volatile emissions during stockpiling, processing, and eventual recycling and, as a result, the organic composition of the fine fraction (and its potential relation to air-entrained particulate matter) may need to be compared with applicable OSHA standards for worker safety and exposure to air-entrained particulate matter limits.	Many standard U.S. EPA methodologies exist for the determination of the organic composition of a material. Organics Composition Using Extraction, Clean-Up and Detection of Organic Compounds Using Gas Chromatographic Methods for Total Petroleum Hydrocarbons (SW-846 8015) and Gas Chromatographic/Mass Spectroscopic Methods for Volatile Compounds (SW-846 8260B), Semivolatile Compounds (SW-846 8270C), Polyaromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) (SW-846 8274A), and Polychlorinated Dibenzodioxins/ Dibenzofurans (PCDDs/PCDFs) (SW-846 8280A or 8290). A more comprehensive listing of organic test methods can be found in SW-846.
Particle Size of Landscaping Material	Particle size analysis is a measure of the size distribution of the material. Particle size analysis should be undertaken if fugitive dust emissions are expected.	From a health and safety perspective, applicable standards for levels of fugitive dusts are listed in 29 CFR, Part 1910. If fugitive emissions are suspected, then the inorganic and organic composition of the material may need to be analyzed and the composition of the fine fraction compared with OSHA Standards listed in 29 CFR, Part 1910, Tables Z-1, Z-2, Z-3, and Z-4.	For particle size determination of 75 microns or greater, ASTM C136 or AASHTO T27 can be used to quantity particle sizes. For particle size determination of less than 75 microns, ASTM D422 can be used.

Table 5-3. Stage 2 laboratory testing recommendations for landscaping materials (continued).

Environmental Property	Comment	Criteria	Test Method
Mineralogical Composition of Landscaping Material	Mineralogical composition testing is useful to determine the inorganic crystalline phases of a material. Determination of inorganic crystalline structure should be performed when the mineralogical composition in the proposed aggregate substitute is unknown (e.g., a new recycled material) or is suspected to have changed over time (e.g., the production or processing facility has undergone modification).	There are no applicable environmental criteria. The presence of certain mineral phases [e.g., chrysotile (asbestos), quartz SiO_2] have health and safety implications. Mineralogical analyses can be used to identify and quantify such phases. Criteria can be found in 29 CFR, Part 1910.	Mineralogy Using x-ray Powder Diffraction or Other Solid State Spectroscopies. Besides x-ray diffraction, there are a number of additional spectroscopies that can be used to characterize the materials (e.g., x-ray, photoelectron spectroscopy, solid state nuclear magnetic resonance spectroscopy, vibrational spectroscopies, etc.).
Inorganic Leaching of Landscaping Material	Inorganic leaching can be used to determine the amount of soluble inorganic components that could be released from the proposed material. Testing of inorganic leaching should be done when high concentrations of inorganic constituents are present, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	Determination of inorganic leaching can be performed to analyze for (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to determine what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to volume ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987, and ASTM D4793. Real-time leaching can be determined by

Table 5-3. Stage 2 laboratory testing recommendations for landscaping materials (continued).

Environmental Property	Comment	Criteria	Test Method
			column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343).
Organic Leaching of Landscaping Material	Organic leaching can be used to determine the amount of soluble organic components in the aggregate substitute. Testing of organic leaching should be done when high concentrations of organic constituents are present, which could be harmful if leached into the environment.	From an environmental perspective, there are no specific criteria. However, if the proposed material can be shown to leach similar levels to reference materials such as (i) accepted construction materials (e.g., asphalt pavements) or native materials (soils, crushed rock) or (ii) "clean soils," or if leachate levels are below applicable groundwater, surface water, or drinking water standards, then the material may not need further testing and should be acceptable from an environmental perspective. For cases where inorganic leaching levels from the proposed material are above selected limits, it may be necessary to examine the pH-dependent behavior of the proposed material (see acid-base behavior). There are no applicable health and safety criteria.	There are no standard methods for determination of organic leaching, but the leaching methods listed below can be used in conjunction with appropriate organic analysis methods to determine (i) total available leaching, (ii) long-term leaching, or (iii) real-time leaching. Total availability leaching is used to tell what fraction of the total composition is available for leaching over extended periods of time. Total availability leaching of inorganics can be determined using the Dutch Total Availability Leaching Test (NEN 7341) or an equivalent method. Long-term leaching can be determined by using batch leaching tests that use high liquid to volume ratios. A variety of methods are available, including U.S. EPA Method 1311 (TCLP), U.S. EPA Method 1320 Multiple Extraction Procedure (MEP), ASTM D3987, and ASTM D4793. Real-time leaching can be determined by column leaching percolation using tests such as the ASTM Column Leach Test (ASTM D4874) or the Dutch Column Test (NEN 7343). The tests can be modified to analyze

Table 5-3. Stage 2 laboratory testing recommendations for landscaping materials (continued).

Environmental Property	Comment	Criteria	Test Method
			organics in the leachates using such methods as EPA 601, 8010, 602, 8020, 8015, 624, 8240, 8260, 524.2 (Volatile Compounds) or EPA 625, 8270 (Acid and Base-Neutral Extractables), EPA 608, 8080 (Pesticides, PCBs), or EPA 8100 (Total Petroleum Hydrocarbons).
Pathogenic Microbiological Analyses of Landscaping Material	Microbial pathogens can be present in certain types of landscaping materials. They may constitute a health hazard. Analyses for microbial pathogens should be used here if it is expected that the proposed landscaping material is from wastewater sludges, animal waste sludges, or municipal solid waste composts, and if the presence of pathogens is likely. The applicant and decision maker can assess the need for these methods, particularly in light of the source of the material and the processing (time and temperature) that the material has been exposed to.	If a landscaping material is to be used as a compost and comes from a process where pathogens (e.g., bacteria, virus, fungi, protozoa) are expected (e.g., municipal waste water sludge, municipal solid waste compost), then the material must have been composted at a high enough temperature (55°C) and a minimum time (at least 3 days for static aerated piles or within vessel, 15 days for windrows, though 21 days can be preferred for all three methods). From an environmental perspective, there are no criteria specific criteria. From a health and safety perspective there are no criteria. However, States may have specific limits for composts derived from wastewater, animal waste sludges, or municipal solid waste composts.	Pathogenic Microbiological Analyses. There are many pathogen detection methods that can be conducted on proposed landscaping materials. These include tests for Total and Fecal coliform and *Escherichia coli* (Standard Methods 9221), fecal streptococcus and enterococcus groups (Standard Methods 9230), pathogenic bacteria such as *Salmonella, Shigella*, etc. (Standard Methods 9260), detection of enteric viruses (Standard Methods 9510), detection of fungi (Standard Methods 9510), and detection of pathogenic protozoa (Standard Methods 9711). New molecular biological methods are being rapidly developed as well.

INTRODUCTION

In a Stage 3 engineering and materials property evaluation, a field testing program must be developed that will provide sufficient data to demonstrate that the proposed material is suitable for use in the proposed application.

To undertake this evaluation, it is recommended that (1) a demonstration testing plan be prepared that delineates the field monitoring requirements, (2) acceptable specifications or performance criteria be established so that the decision-making process can be completed, and (3) the data be statistically evaluated to determine if specifications are met or if performance is similar to that of appropriate reference materials.

Figure 6-1 provides a flowchart highlighting the steps in a Stage 3 engineering field evaluation program. Included in Figure 6-1 is reference to Tables 6-1 through 6-14. These tables provide a listing of recommended short-term and long-term field monitoring methods for selected highway applications.

FIELD DEMONSTRATION PLAN

The decision as to how to monitor a field trial is primarily dependent on the selection of key design, construction, and long-term performance parameters for field evaluation. It is important to select performance parameters that can be monitored in the field in such a manner that sufficient data are provided to evaluate the performance of the product.

Once these key parameters are selected, field monitoring activities can be planned to quantify these engineering parameters. Field monitoring activities typically fall into one of three categories: (1) material sampling and laboratory analysis, (2) visual observations, and (3) measurement of in-place performance indicators.

Material sampling and laboratory analysis during field trials are primarily used to reconfirm that all material characteristics and design assumptions are still valid. The degree of material sampling and laboratory testing will, in most cases, be dependent on the expected variance (or variability) that the material may exhibit for key performance parameters. Visual observations refer to qualitative observations made by a field inspector to assist in assessing the manner in which the material affects the production, storage, transportation, and placement of the product relative to conventional materials. The measurement of in-place performance indicators refers to a category of activities in which some form of nondestructive testing of the in-place product is used as a measure to assess product performance. Some examples include settlement readings, deflection measurements, and strength monitoring.

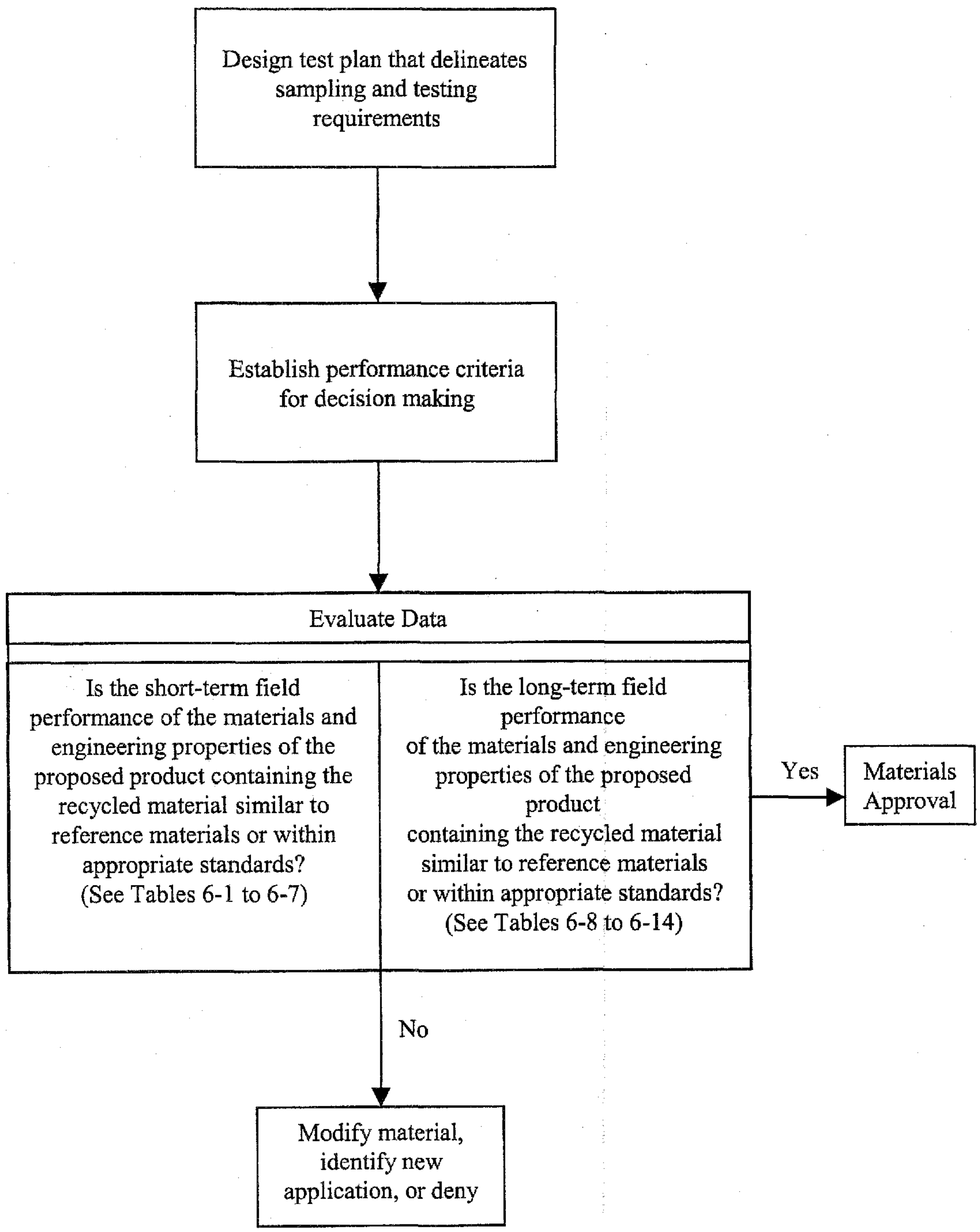

Figure 6-1. Engineering and materials properties field evaluation flowchart.

Field monitoring activities will differ, depending on the type of application being proposed. Recommended field monitoring activities are presented in the following subsections for each highway application presented in these guidelines. Tables 6-1 through 6-14 present a description of recommended short-term and long-term engineering field monitoring activities for each application.

Asphalt Concrete

Table 6-1 provides a description of short-term monitoring activities recommended to assess the performance of proposed materials that are planned for use in the construction of asphalt concrete pavements. Some key short-term engineering performance parameters that should be monitored (for either hot mix or cold mix pavements) include handleability, compactability, stability, and durability.

Table 6-2 provides a description of long-term monitoring activities recommended to assess the long-term performance of proposed materials that are planned for use in the construction of asphalt concrete pavements. Some key engineering performance parameters that should be monitored include stability, durability, permeability, wear resistance, stripping resistance, frictional resistance, and ride quality.

Portland Cement Concrete

Table 6-3 provides a description of short-term monitoring activities recommended to assess the short-term performance of proposed materials that are planned for use in the construction of portland cement concrete pavements. Some key engineering performance parameters that should be monitored include workability, strength development, frost susceptibility, and reactivity.

Table 6-4 provides a description of long-term monitoring activities recommended to assess the long-term performance of proposed materials that are planned for use in the construction of portland cement concrete pavements. Some key long-term engineering performance parameters that can be monitored to assess the performance of hardened portland cement concrete include strength development, structural stability, frost susceptibility, reactivity, frictional resistance, and ride quality.

Granular Base

Table 6-5 provides a description of short-term monitoring activities recommended to assess the performance of proposed materials that are planned for use in the construction of a granular base. Some key engineering performance parameters that should be monitored include handleability, moisture density characteristics, compactability, and drainage capability.

Table 6-6 provides a description of long-term monitoring activities recommended to assess the long-term performance of proposed materials that are planned for use in the construction of a granular base. Some key engineering performance parameters that should be monitored include stability, permeability, and frost susceptibility.

Stabilized Base

Table 6-7 provides a description of short-term monitoring activities recommended to assess the short-term performance of proposed materials that are planned for use in the construction of a stabilized base. Some key engineering performance parameters that should be monitored include handleability, moisture-density characteristics, compactability, stability, and strength development.

Table 6-8 provides a description of long-term monitoring activities recommended to assess the long-term performance of proposed materials that are planned for use in the construction of a stabilized base. Some key engineering performance parameters that should be monitored to assess the performance of a new material include stability and strength development, and freeze-thaw and wet-dry susceptibility.

Flowable Fill

Table 6-9 provides a description of short-term monitoring activities recommended to assess the performance of proposed materials that are planned for use in the production and placement of flowable fill. Some key engineering performance parameters that should be monitored include flowability, hardening time, strength development, and dimensional stability.

Table 6-10 provides a description of long-term monitoring activities recommended to assess the performance of proposed materials that are planned for use in the production and placement of flowable fill. Some key engineering performance parameters that should be monitored to assess the hardened flowable fill include strength development, hardened density, frost susceptibility, and dimensional stability.

Embankments or Fills

Table 6-11 provides a description of short-term monitoring activities recommended to assess the performance of proposed materials that are planned for use in the construction of embankments or fills. Some key engineering performance parameters that should be monitored include handleability, moisture-density characteristics, compactability, shear strength, consolidation characteristics, and bearing capacity.

Table 6-12 provides a description of long-term monitoring activities recommended to assess the long-term performance of proposed materials that are planned for use in the construction of embankment or fills. Some key engineering performance parameters that should be monitored include consolidation or settlement behavior, slope stability, bearing capacity, and frost susceptibility.

Landscaping Materials

Table 6-13 provides a description of short-term monitoring activities recommended to assess the performance of proposed materials that are planned for use as a landscaping material. A key engineering performance parameter that should be monitored includes handleability.

Table 6-14 provides a description of long-term monitoring activities recommended to assess the long-term performance of proposed materials that are planned for use as a landscaping material. Key engineering performance parameters that should be monitored include erodability and vegetative growth.

ESTABLISH ACCEPTABLE CRITERIA

During the design and/or approval of the test plan, the decision maker will need to determine the criteria on which an approval will be based. Two methods are available for use in such an evaluation. The first includes the use of existing ASTM or AASHTO specifications or criteria imposed by local jurisdictions (e.g., State DOTs) when they are available. In cases where no definitive criteria exist, the decision maker can compare the field performance of the proposed material with that of a reference material (e.g., conventional construction material) to assess the relative performance of the proposed reference material. This can be done by constructing companion control sections of comparable design using only conventional materials and comparing the performance of the two sections.

EVALUATE FIELD ENGINEERING AND MATERIALS DATA FOR POSSIBLE APPROVAL

As illustrated in Figure 6-1, to evaluate field demonstration results, it is recommended that comparisons to control test sections or appropriate standards established by ASTM, AASHTO, or the State DOTs be made to assess the suitability of the proposed material in the selected specification. Statistical comparisons between proposed material test section and the control section or appropriate standards will be required. Examples of the types of statistical comparisons that can be made are presented in Chapter 9.

Table 6-1. Asphalt paving short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Handleability refers to the manner in which plant-mixed paving material behaves immediately after mixing, during stockpiling, and when it is being dumped and spread into place at the project site. It is affected by the grading of the aggregates in the mix, the characteristics of the asphalt binder, and, in the case of hot mix pavements, the ability of the mixture to remain within the proper temperature range for achieving the desired compaction.		Observe material consistency, asphalt coating of aggregate particles, ease and uniformity of spreading the mixture, and, in the case of hot mix, the ability of the mix to maintain a specified temperature range.	
Compactability refers to the manner in which the paving material responds under the action of compaction equipment, along with the relative ease (or difficulty) that is encountered in achieving a specified target density on the job site. It is influenced by the gradation of the aggregates in the paving mix, the particle shape of the aggregates, and the percentage of binder in the mix. For hot mix asphalt, the temperature of the paving material also directly affects its compactability.	Core samples taken from the compacted pavement can be used to confirm that the mix has been compacted to the maximum density value, which was determined in the mix design.	Observe movement of the paving material under (or ahead of) the action of a roller, response to various types of compaction equipment (static vs. vibratory), number of roller passes needed to fully compact the paving material, possible breakdown of aggregate particles during compaction, and surface texture and uniformity following compaction.	Monitor for compacted thickness of the mix and in-place density and percent compaction of the mix by using a nuclear density gauge.

Table 6-1. Asphalt paving short-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Stability refers to resistance to movement or deformation under loading conditions once the material has been compacted in place. It is influenced by the size distribution and shape of the aggregate particles in the paving mix as well as the binder content of the mix.	Grab samples of freshly mixed asphalt paving material samples taken at the mixing plant can be collected to verify that the asphalt content, air voids content, compacted density, stability, and flow values (if applicable) of the mix are essentially in accordance with those that were developed earlier for the approved design mix (Marshall, Hveem, or Superpave).		
Durability refers to the ability of the material to resist damage from repeated cycles of wetting and drying, freezing and thawing (in those areas where subfreezing temperatures occur), and long-term oxidation of the binder due to prolonged exposure to ultra-violet rays. The percentage of air voids in the compacted paving mix can significantly affect pavement durability.	Wet-dry or freeze-thaw testing can be performed by molding and testing grab samples in accordance with standard asphalt testing methods.		

Table 6-2. Asphalt paving long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Stability refers to the ability of the paving material to resist movement or deformation under traffic loading conditions.	Asphalt core samples may be collected and analyzed periodically for compacted density and resilient modulus as a means of evaluating stability. Changes in aggregate gradation, asphalt content, or mix design properties can be monitored and compared over time with mix design data.	Observe signs of cracking, shoving, rutting, or other surface distress, especially in areas subjected to stopping or turning movements, particularly with heavy vehicle traffic, such as trucks and/or buses.	A series of deflection measurements can be taken periodically within each principal travel lane of an asphalt pavement using either a Benkleman beam or a falling weight deflectometer with a computerized readout of deflection values from four or five sensor locations. The resultant deflection data can be used to determine the deflection and resilient modulus of each pavement layer. Readings taken near areas of surface distress can be interpreted to determine if the distress is confined to the asphalt paving material or has been caused by a failure in the base course or the underlying subgrade soil.
Durability refers to the ability of the paving material to resist damage from repeated cycles of wetting and drying, freezing and thawing (in those areas where subfreezing temperatures occur), and long-term oxidation of the binder due to prolonged exposure to ultra-violet rays.	Periodically collect core samples and extract the asphalt cement binder (from hot mix asphalt) and test for viscosity and penetration to assist in the evaluation of pavement durability.	Observe signs of bleeding, stripping, settlement, potholes, or expansive cracking due to the repeated action of wetting and drying cycles, or freezing and thawing cycles.	
Permeability refers to the rate at which water passes through the pavement. It is related to the densification of the paving material and the arrangement of internal void spaces.	Periodically collect core samples and test for permeability as a means of evaluating the relative permeability of the pavement over time.	Observe signs of water seepage that may appear within the pavement surface from time to time or poor drainage, as evidenced by puddles.	

Table 6-2. Asphalt paving long-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Wear Resistance refers to the ability of the paving material to resist abrasion or surface damage due to repeated tire action or vehicle loadings.	Recover core samples and inspect the aggregate portion; determine the aggregate type and mineralogy, particle shape, percent crushed faces, and other pertinent information (such as surface texture, porosity, and absorption); compare with original samples.	Inspect the pavement for signs of abrasion or raveling.	
Stripping Resistance refers to the ability of the paving material to maintain a coating of asphalt on the surface of aggregate particles in the mix that are exposed to repeated tire action.	Conduct stripping tests on recovered core samples.	Inspect the pavement for asphalt stripping and aggregate polishing.	
Frictional Resistance refers to the ability of the paving material to resist the polishing of the exposed surface of aggregate particles in the mix and maintain the friction between the pavement surface and the tires of vehicles using the road.	Test pavement samples in the laboratory to determine a British pendulum number (BPN).	Inspect the pavement for aggregate polishing, which is indicative of a potential deterioration of frictional resistance.	Monitor frictional resistance of a pavement using a locked wheel skid trailer.
Ride Quality refers to the relative smoothness of the pavement surface and its ability to provide a safe, comfortable ride to the vehicle user.			Monitor the ride quality of an asphalt pavement using a profilograph; such devices are capable of recording the smoothness of a pavement surface.

Table 6-3. Portland cement concrete short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Workability refers to the relative ease in which concrete discharges from a ready-mix truck, places it within the required lines and grades, and provides the proper finish. It is influenced by the water-cement ratio of the mix, the gradation and particle shape of the aggregates in the mix, and any admixtures that may have been incorporated into the mix.	Collect samples of plastic concrete and measure the slump and air voids content of the mix.	Observe material consistency, ease of production at specified mix designs, ease of placement, ability to move the concrete, stiffness or harshness of the mix, extent of bleeding, ease of finishing the concrete, the amount of time to initial setting of the concrete, and the need for water addition on site to improve workability.	
Strength Development refers to the short-term (7 and/or 28 days) unconfined compressive strength of the concrete after hardening. It is largely a function of cement content, water-cement ratio, aggregate characteristics, and any admixture that may be incorporated into the mix.	Conduct unconfined compressive strength tests on production samples.		Use a Swiss hammer device to drive steel spikes into the concrete; the resistance to the penetration of the spikes can be correlated to the in-place compressive strength of the concrete.
Frost Susceptibility refers to the ability of the concrete to resist damage from repeated cycles of freezing and thawing, in those areas where subfreezing temperatures occur. It is affected to a great extent by the air content of the mix, which results from the addition of an air-entraining admixture into the mix.	Subject hardened core samples to cyclic freeze-thaw testing.		

Table 6-3. Portland cement concrete short-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Reactivity refers to the susceptibility of the concrete, or components of the concrete to adverse chemical reactions that may occur within the concrete. Such adverse chemical reactions can produce significant volume changes, interfere with the hydration of the cement, or produce harmful chemical by-products.	Test collected samples for alkali-aggregate reactivity and sulfate-induced expansion using mortar bar expansion tests; test proposed material for presence of deleterious materials (clays and sulfate).		

Table 6-4. Portland cement concrete long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Strength Development refers to the long-term (greater than 28 days) and ultimate unconfined compressive strength (greater than a year) of the portland cement concrete.	Test core samples for hardened density and unconfined compressive strength to monitor long-term development.		
Structural Stability refers to degree to which the concrete pavement distributes applied wheel loadings to the supporting subbase and subgrade without distress or undue surface deflections.			A series of deflection measurements can be taken periodically within each principal travel lane of an asphalt pavement using either a Benkleman beam or a falling weight deflectometer with a computerized readout of deflection values from four or five sensor locations. The resultant deflection data can be used to determine the deflection and resilient modulus of each pavement layer. Readings taken near areas of surface distress can be interpreted to determine if the distress is confined to the asphalt paving material or has been caused by a failure in the base course or the underlying subgrade soil.
Frost Susceptibility refers to the ability of the concrete to resist damage from repeated cycles of freezing and thawing, in those areas where subfreezing temperatures occur. It is affected to a great extent by the air content of the mix, which results from the addition of an air-entraining admixture into the mix.	Subject collected core samples to cyclic freeze-thaw testing.	Periodically inspect the concrete for frost heaving.	

Table 6-4. Portland cement concrete long-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Reactivity refers to the susceptibility of the concrete, or components of the concrete, to adverse chemical reactions that may occur within the concrete. Such adverse chemical reactions can produce significant volume changes, interfere with the hydration of the cement, or produce harmful chemical by-products.		Periodically inspect the concrete to determine the occurrence and extent of any map cracking, scaling, popouts, faulting, surface defects, or staining that would be indicative of reactivity.	
Frictional Resistance refers to the ability of the paving material to resist the polishing of the exposed surface of aggregate particles in the mix and maintain the friction between the pavement surface and the tires of vehicles using the road.			Measure resistance using a locked wheel skid trailer.
Ride Quality refers to the absence of pavement surface irregularities and the ability of the pavement to provide a safe, smooth ride.			Measure ride quality of a concrete pavement using a profilograph.

Table 6-5. Granular base short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Handleability refers to the manner in which the material behaves during stockpiling and when it is loaded, dumped, and spread into place at the project site.		Observe difficulties or ease of loading or unloading, spreading and grading, the presence of possible clumps or over-size particles, and compare with that of conventional granular base aggregate materials.	
Moisture Density Characteristics refer to the relationship of moisture content to the compacted density of the material.	Granular base materials are typically cohesionless, free draining materials that exhibit compacted densities that are not extremely sensitive to moisture content. One-point Proctor tests can be undertaken prior to construction to confirm the density characteristics of the proposed material.		Use the sand-density cone method, the water-balloon method, or a nuclear density gauge to measure in-place density.
Compactability refers to how the material responds under the action of compaction equipment, as well as the relative ease or difficulty of achieving a target density in the field.		Observe and record such items as movement of the material under (or ahead of) the action of a roller, number of roller passes needed to fully compact the material, possible breakdown of particles during compaction, and moisture conditions at the surface of the material following compaction.	Directly measure compacted layer thickness.
Drainage Capability refers to the ability of a base course material to provide suitable drainage after compaction and following rainfall events.	Test material in the laboratory for particle size distribution and permeability.	Observe drainage of surface water following rainfall and any evidence of water seepage during dry periods, which may indicate that water is not properly draining through the base course.	

Table 6-6. Granular base long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Stability refers to the ability of the granular base material to resist movement and to transmit load from overlying pavements to the subgrade.	Measure the particle size distribution before and after construction, moisture content, and compacted density. Increases in the percentage of fines (material passing the No. 200 sieve) over time indicate a breakdown of the base course under traffic loading and/or weather, which could reduce the load carrying capacity of the base material.	Observe alligator cracking, rutting, potholes, or localized settlements of the roadway surface ordinarily indicative of a loss of support within the base layer.	Periodic deflection measurements can be taken within each principal travel lane of the roadway; measurements are ordinarily obtained by using a Benkleman beam or a falling weight deflectometer with a computerized readout of deflection values from four or five sensor locations. The resultant deflection basin data are then analyzed by software to determine the deflection and resilient modulus of each pavement layer. By taking a series of deflection measurements over time, changes in the stability or load carrying capability of the base course can be detected.
Permeability refers to the ability of a base course material to conduct water and prevent eventual saturation of the base, which is often accompanied by damage due to freezing and thawing.	Measure the particle size distribution and conduct permeability testing on core samples over time. Changes in the particle size distribution of the granular base material usually involve an increase in the percentage of fines (material passing the No. 200 sieve), either because of particle breakdown in the base course or pumping of subgrade soil into the base.	Observe alligator cracking and/or seepage of the roadway surface that may be attributable to inadequate or poor drainage within the granular base material. Alligator cracking is ordinarily a clear indicator of a granular base failure that may be attributable to saturation of the base, mixing of underlying subgrade soil with the base course material, or both.	
Frost Susceptibility refers to the ability of a base course to resist damage from either cyclic freezing and thawing, in those areas where subfreezing temperatures occur.	Can be evaluated by periodic laboratory testing of granular base samples for resistance to freezing and thawing.	Observe frost heaving or water seepage of the pavement surface that may be indicative of freeze-thaw or wetting-drying problems.	

Table 6-7. Stabilized base short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Handleability refers to how well mixed-in-place material is able to be spread and blended together on site; also refers to the way plant-mixed material behaves during stockpiling or when it is loaded, dumped, and spread into place at the project site. It is generally influenced by the particle size distribution and moisture content (for calcium-based binders) of the constituent materials and how well the materials are mixed.		Observe moisture characteristics (too dry, compactable, or too wet), presence of oversize or deleterious components in the material, uniformity or consistency of the mixture, ease or difficulty in handling or spreading, tendency to harden or set too rapidly, behavior under adverse weather conditions (heavy rain or freezing temperatures), and handling compared with conventional stabilized base mixtures (such as soil-cement).	
Moisture-Density Characteristics refer to the relationship of the moisture content to the compacted density of the material and are influenced by the particle size, particle interlock, percentage of binder or reagent, compactive effort, and the amount of fine particles in the mix. This parameter is applicable for calcium-based binders.	A one-point Proctor test can be performed in the field on the freshly mixed material to provide an indication of whether the compacted material will have a moisture content and dry density that is within the specified range of compaction.	Observe whether the moisture content of the stabilized base material is within a compactable range prior to loading and delivery of the material to the job site. If too dry, it must be spread out and sufficient water added to bring it within a compactable range. If too wet, it should be blended with dry (or drier) material as soon as possible to avoid time delays that could result in the material setting before it has been delivered to the project site (or mixed in-place) and compacted.	
Compactability refers to how the material responds under the action of compaction equipment, along with the relative ease or difficulty of the material to achieve a target density in the field.		Observe and measure the number of roller passes needed to achieve the specified percentage of compaction, ability to achieve compaction using different types of compaction equipment, movement of the material under (or ahead of) the action of a roller, variations in the material over time, possible breakdown of particles during compaction, moisture conditions at the surface of the	Measure the compacted layer thickness and in-place density, moisture content, and percent compaction. This would typically be undertaken using the sand-density cone method, the water-balloon method, or by means of a nuclear density gauge.

Table 6-7. Stabilized base short-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
		material following compaction, and the ability of the compacted material to support imposed wheel loadings or to resist erosion.	
Strength Development and Stability refer to the ability of a material to resist movement or deformation under loading conditions once it has been compacted in place. It is influenced by the size distribution and shape of the aggregate particles in the mix, the particle interlock capability of the aggregate particles, the compacted density of the mix, and the relative amount and cementing and strength development of the matrix.	Freshly mixed samples of the stabilized base material can be collected and tested for unconfined compressive strength (for calcium-based binders) and stability (for asphaltic binders) to validate the original mix design data.	Observe rutting in the compacted material resulting from the passage of construction traffic (trucks, rollers, paving equipment, etc.) over the material following compaction, but before the placement of an asphalt or concrete pavement on top of the base.	Monitor for compressive strength and/or bearing strength by using a cone penetrometer or a Clegg impact tester, either of which can be correlated with bearing capacity, or using a plate bearing test.

Table 6-8. Stabilized base long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Strength Development and Stability refer to the ability of the compacted stabilized base material to gain strength over time, given the proper curing conditions and the ability of the compacted stabilized base material to resist movement and degradation under the action of repeated wheel loadings and transmit loadings to the subgrade.	Monitor by determining unconfined compressive strength of core samples taken from the pavement at different time periods. Unexpectedly low compressive strength development over time may be caused by a number of factors, including inadequate compaction, unfavorable curing conditions, insufficient reagent addition during mixing, poor weather during installation, localized areas of poor drainage, or the presence of deleterious materials such as sulfates and clays. Monitor by testing moisture content and compacted density. Increases in the moisture content of the base material, accompanied by reduced values for compacted density over time, may be a signal that poor drainage and cracking could occur within the base layer.	Observe cracking, volumetric expansion, or the formation of potholes in the roadway surface. In some cases, poor or inadequate strength development can be caused by insufficient compaction or exposure to heavy precipitation during the construction period. Observe localized settlement, surface depressions, or alligator cracking of the pavement normally indicative of a base failure that may be attributable to the loss of stability within the stabilized base layer.	Periodic deflection measurements can be taken within each principal travel lane of the roadway. Deflection measurements are ordinarily obtained by means of a Benkleman beam or a falling weight deflectometer with a computerized readout of deflection values from four or five sensor locations. The resultant deflection basin data are then analyzed by software to determine the deflection and resilient modulus of each pavement layer. By taking a series of deflection measurements over time, changes in the stability or load carrying capability in different sections of the stabilized base can be detected from an interpretation of the deflections at various locations of the base course.
Frost Susceptibility refers to the ability of the compacted stabilized base material to gain a sufficient amount of strength to resist damage from repeated cycles of freezing and thawing, in those areas where sub-freezing temperatures occur.	Monitor by determining the resistance of stabilized base material core samples to freeze-thaw cycles using standard testing procedures. Any surface heaving or disturbance of the upper portions of core specimens in areas of subfreezing temperature could be evidence that frost heaving may have occurred because of cyclic freezing and thawing.	Observe evidence of surface heaving or expansive cracking of the pavement, which may indicate that the stabilized base layer has been damaged by frost.	

Table 6-8. Stabilized base long-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Wet-Dry Susceptibility refers to the ability of the compacted stabilized base to resist damage from wetting and drying cycles.	Monitor by determining the resistance of the stabilized base material core to wetting and drying cycles using standard testing procedures. Any surface distress (cracking) could be evidence that the base is impacted by these cycles.	Observe evidence of expansive cracking or settling that may indicate a damaged base.	

Table 6-9. Flowable fill short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Flowability refers to how well a mixture will flow when being heated.	Measure the flow of the material through a standard flow cone, a slump test, or recently developed inverted cylinder test.	Observe material consistency, ease of flow into openings and around obstructions, possible need for anchoring lighter weight piping, seepage through pipe joints, and self-leveling of flowable fill.	
Hardening Time refers to the time required for the mixture to harden sufficiently so that manpower and construction equipment can be placed upon it.	Perform laboratory tests to determine the amount of time it takes the fluid material to harden. A pocket penetrometer can be used to test cylindrical samples and determine how long it takes for the hardened material to develop a predetermined penetration resistance.	Observe the length of time before the flowable fill has hardened enough to support the weight of a person; usually 3 to 4 hours.	Measure with a pocket penetrometer; pocket penetrometer readings can be correlated to a bearing strength or unconfined compressive strength value that can safely support the weight of an average size person.
Strength Development refers to the short-term unconfined compressive strength of the flowable fill mixture after hardening.	Determine the unconfined compressive strength of flowable fill material samples that have hardened and cured for various time periods.		Measure by preparing cylindrical test specimens when placing the flowable fill and storing the test specimens in sealed containers in a protected manner at the site; the specimens can be recovered and returned to the laboratory for unconfined compressive strength testing at predetermined short-term time intervals, probably up to 28 days.
Dimensional Stability refers to the ability of the hardened flowable fill to resist changes in volume resulting from settlement or shrinkage.	Can be evaluated in the laboratory by measuring the effect of length change over time using mortar bar expansion tests.	Observe potential migration of bleed water to the top surface of the flowable fill, the formation of shrinkage cracks, and evidence of settlement or shrinkage of the material after it has hardened.	Measure by taking level readings at the top surface of the material to determine if there has been any settlement or expansion.

Table 6-10. Flowable fill long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Strength Development refers to the long-term and ultimate unconfined compressive strength of the hardened flowable fill material.	Test for unconfined compressive strength (as well as triaxial shear strength) at various ages. To facilitate this testing evaluation, it is recommended that cylindrical samples of the flowable fill material be prepared during the construction phase, stored in a protected manner at the project site, and removed and tested in a laboratory at pre-determined intervals in order to monitor the development of compressive strength over time.	Observe settlement or cracking, which may indicate poor strength development or possibly poor subgrade soil conditions.	
Hardened Density refers to the unit weight of the flowable fill material after it has hardened.	Monitor by measuring the unit weight.		Monitor density by a nuclear density gauge if the surface of the flowable fill is accessible.
Frost Susceptibility refers to the possibility of the hardened flowable fill incurring surface damage or deterioration from the effects of freezing and thawing.	Monitor by measuring the freeze-thaw resistance of the sample using standard testing methods.	Observe frost heave or expansive cracking of the overlying ground or pavement surface.	
Dimensional Stability refers to the ability of the hardened flowable fill to resist changes in volume from settlement or shrinkage.	Monitor by length comparator testing of prepared laboratory samples over an extended period.		Monitor periodic elevation readings, using either the exposed top surface of the flowable fill, settlement plates mounted on top of the flowable fill, or designated points on the surface of a roadway and/or structure that is placed directly above the top surface of the flowable fill.

Table 6-11. Embankment and fill short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Handleability refers to the manner in which an embankment or fill material behaves during stockpiling, or when it is loaded, dumped, and spread into place at the project site. It is influenced by the particle size distribution, moisture content, and plasticity characteristics of the fill material.		Observe moisture characteristics (too dry, compactable, or too wet), presence of possible oversize components in the material, ease or difficulty in handling and spreading compared with conventional embankment or fill materials.	
Moisture-Density Characteristics refer to the relationship of moisture content to the compacted density of the material. They are influenced by particle sizing, porosity, and compactive effort.	Verify the design values for optimum moisture and maximum densities by measuring the material's compacted density using a one-point Proctor test in the field.	Observe whether the moisture content of the stockpiled material is within a compactable range prior to delivery to the job site. If too dry, spread out and add sufficient water to bring it within a compactable range. If too wet, spread out and dry to within a compactable range.	Measure in-place density and moisture content by using the sand-density cone method, the water-balloon method, or nuclear density gauge.
Compactability refers to how the material densifies under repeated passage of various types of compaction equipment. It also encompasses the relative ease or difficulty with which a given material is able to achieve a target density when being placed and compacted in the field, and whether or not the material breaks down under compactive effort.		Observe the number of roller passes needed to achieve the specified percentage of compaction, ability to achieve compaction using different types of compaction equipment, movement of the material under (or ahead of) the action of a roller, variations in the material over time, possible breakdown of particles during compaction, moisture conditions at the surface of the material following compaction, and ability of the compacted material to resist erosion.	Monitor direct measurement of loose and compacted layer thickness.
Shear Strength refers to the ability of a material to resist deformation resulting from the force of applied loadings. It is derived from cohesion or internal friction, or both.	Perform direct shear or triaxial compression test on the material.		

Table 6-11 Embankment and fill short-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Consolidation Characteristics refer to compression or settlement of a material under the influence of an applied loading. The rate of settlement is affected by the void ratio, moisture content, and permeability of the material. It can be short term (during and shortly after construction) or long term, which may continue for months or years after construction.	Perform a one-dimensional consolidation test.		Monitor by means of settlement plates or slope inclinometers, or both.
Bearing Capacity refers to the ability of a compacted material to support and distribute loadings applied directly to its surface without undergoing localized shear failure or unacceptable settlement. The bearing strength is used for pavement thickness design and is related to the shear strength of the material.	Measure the California Bearing Ratio (CBR) of a material sample in the laboratory. It can also be calculated if the cohesion and friction angle of the material are known.		Conduct a plate bearing test.

Table 6-12. Embankment and fill long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Consolidation or Settlement Behavior refers to the ability to resist volume changes resulting from applied loading.	Can be monitored by comparing field settlement values with calculated values determined from laboratory consolidation testing. Undisturbed (Shelby tube) samples can be obtained to perform consolidation tests.	The formation of surface depressions or cracking of the overlying pavement can be an indication that settlement is occurring. Widening cracks or growing depressions in pavement surfaces may indicate localized settlements in an embankment or fill.	Periodic level readings can be recorded on the top of pipes that are fixed to settlement plates or platforms. Such plates or platforms can be installed at various locations and elevations within the fill material during construction; an alternate method includes readings taken from slope inclinometers, which may be installed at selected depths within the fill during construction. Readings can be used to calculate settlements by determining changes in the slope of the inclinometers at various depths within the embankment or fill.
Slope Stability refers to the ability of a material to resist movement or deformation along or beneath the slopes of the embankment and is related to the shear strength of the compacted material.	Undisturbed (Shelby tube) samples can be obtained for the analyses of slope stability. It can be performed by evaluating the laboratory results from triaxial strength, permeability, and direct shear strength testing.	Sliding or ground sloughing along the surface of side slopes may be a sign of impending slope failure, particularly if the sloughing is observed near the base of the embankment slope. Water seepage from the base or side slopes of an embankment would ordinarily be indicative of potential for slope failure.	Piezometer readings indicate variations in ground water levels to hydrostatic pressure within an embankment or fill and may be indicative of increased stresses or potential instability within an embankment or rill.
Bearing Capacity refers to the ability of the embankment or fill material to support the weight of the embankment or fill material and to support the weight of vehicular traffic or structures placed upon it.			The blow counts from the split-spoon sampling of the fill material can be correlated to the unconfined compressive strength and/or the bearing capacity of the material.

Table 6-12. Embankment and fill long-term field monitoring recommendations (continued).

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Frost Susceptibility refers to the ability of the material to resist volume changes or damage (heaving) from the freezing and thawing of moisture within the voids of the material.		Premature pavement deterioration (expansion cracking) can be a signal that the embankment may be expanding because of frost heave.	

Table 6-13. Landscaping material short-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Handleability refers to the manner in which a landscaping material behaves during stockpiling, when it is loaded, dumped, and spread into place at the project site. It is influenced by the particle size distribution, moisture content, and plasticity characteristics of the fill material.		Observe moisture characteristics (too dry, compactable, or too wet), presence of possible oversize components in the material, ease or difficulty in handling and spreading compared with conventional landscaping materials.	

Table 6-14. Landscaping material long-term field monitoring recommendations.

Performance Parameter	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Erodibility refers to a loss of most landscaping material with time.		The observed migration of landscaping material from the finished graded structure would indicate an erodible material.	Periodic surveyed level readings can be recorded on the finished grade to record the actual loss of material (height).
Vegetative Growth refers to the suitability of the material to support vegetation.		The observed rate of growth can be a good indicator of the suitability of the material for supporting vegetative growth. A control material can be used as a reference material.	Actual vegetative mass can be recorded by collecting performance surface samples.

INTRODUCTION

In a Stage 3 environmental, health, and safety evaluation, a field testing program must be developed that will provide sufficient data to demonstrate that the proposed material is suitable for use in the proposed application.

To undertake this evaluation, it is recommended that (1) a demonstration test plan be prepared to identify the methods and procedures to be used in evaluating the material and its proposed application, (2) acceptable performance criteria be established, and (3) the data be statistically evaluated to determine if appropriate criteria are being met.

Figure 7-1 provides a flowchart highlighting the steps in a Stage 3 environmental, health, and safety field evaluation program. Included in Figure 7-1 is reference to Tables 7-1 through 7-14. These tables provide a listing of recommended short-term and long-term field monitoring methods for selected highway applications.

FIELD DEMONSTRATION PLAN

The decision as to how to monitor a field trial is primarily dependent on the identification of environmental, health, and safety issues that could result from the introduction of a new or substitute material into the production and/or construction process and long-term presence of the product in the environment during and after its service life.

Once these issues are identified, field monitoring activities can be selected to quantify the environmental, health, and safety issues that have been raised. Field monitoring activities typically fall into one of three categories: material sampling and laboratory analysis, visual observations, and measurement of in-place performance indicators.

Material sampling and laboratory analysis during field trials are primarily used to reconfirm that all material characteristics and design assumptions are still valid. The degree of material sampling and laboratory testing will, in most cases, be dependent on the expected variance (or variability) that the material may exhibit for key performance parameters. Visual observations refer to qualitative observations made by a field inspector to assist in assessing the manner in which the material affects environmental, health, and safety issues associated with the production, storage, transportation, and placement of the product relative to conventional materials. The measurement of in-place performance indicators refers to a category of activity in which some form of nondestructive testing of the in-place product is used as a measure to assess product performance. Some examples include runoff or leachate monitoring, groundwater monitoring, soil moisture monitoring with suction lysimeters, fugitive particle collection, and the use of personal air samplers.

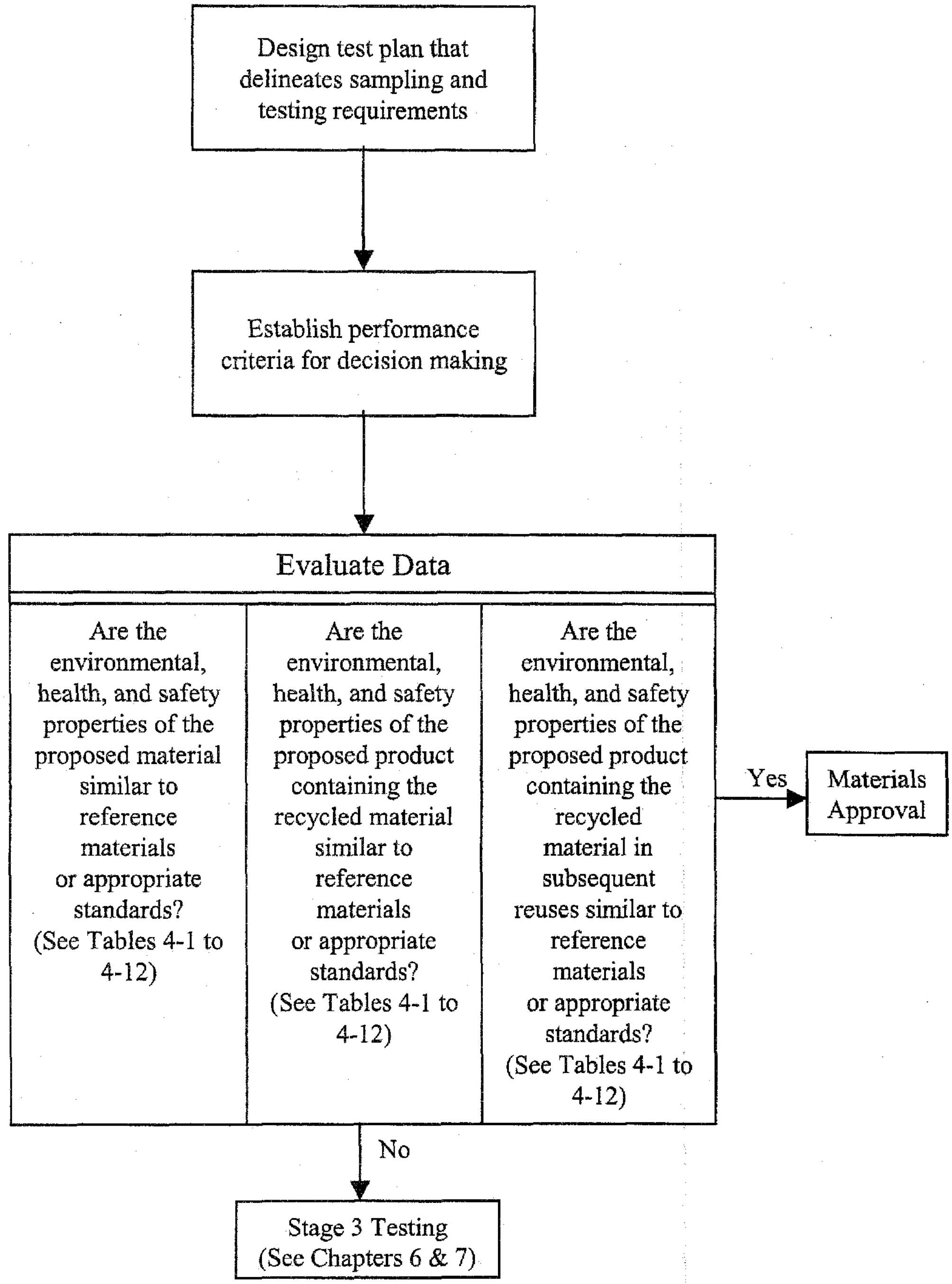

Figure 7-1. Environmental, health, and safety properties field evaluation flowchart.

Field monitoring activities will differ, depending on the type of application being proposed by the applicant and the specific operation associated with each application. Recommended field monitoring activities are presented in the following subsections for each highway application presented in these guidelines. Tables 7-1 through 7-14 present a description of recommended short-term and long-term environmental, health, and safety field monitoring activities for each application.

Asphalt Concrete

Short-term environmental, health, and safety issues associated with the construction of an asphalt pavement may occur during production, storage, transportation, or placement of the pavement. Asphalt pavements can be produced at either a hot mix or a cold mix production plant. Material operations at each type of plant may differ, but field construction operations are similar.

At a hot mix plant, the basic operations that occur include stockpiling, aggregate feeding, mineral filler feeding, drying and heating, asphalt cement heating and feeding, plant mixing, and truck loading. At a cold mix plant, the basic operations include stockpiling, aggregate feeding, asphalt emulsion feeding, plant mixing, aeration, and truck loading. At the construction site, truck unloading, spreading, and compaction of the paving materials are common to both mix types.

Table 7-1 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in the construction of asphalt concrete pavements. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and asphalt plant stack emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the asphalt pavement.

Table 7-2 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in the construction of asphalt concrete pavements. During the post-construction period, four long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, runoff quality, and surface water quality.

Portland Cement Concrete

Short-term environmental, health, and safety issues associated with the construction of a portland cement concrete pavement may occur during production, storage, transportation, or placement of the pavement.

At the production facility (ready-mix plant), the basic operations that occur include aggregate stockpiling, loading and feeding, portland cement and mineral admixture feeding, water addition, plant mixing, truck loading, and mixing. At the construction site, operations include truck discharge, placing and spreading, finishing, and curing.

Table 7-3 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in the construction of portland cement concrete pavements. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and fugitive dust emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the concrete pavement.

Table 7-4 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in the construction of portland cement concrete pavements. During the post-construction period, four long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, runoff quality, and surface water quality.

Granular Base

Short-term environmental, health, and safety issues associated with the construction of a granular base using a substitute material may occur during blending operations, storage, transportation, spreading and grading, compacting, and sealing of the pavement.

Table 7-5 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in the construction of granular bases. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and fugitive dust emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the granular base.

Table 7-6 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in the construction of granular bases. During the post-construction period, three long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, and surface water quality.

Stabilized Base

Short-term environmental, health, and safety issues associated with the construction of a stabilized base using a substitute material may occur during production, storage, transportation, spreading and grading, compacting, and sealing of the pavement.

The operations associated with the construction of a stabilized base are dependent on the type of binder used (calcium or asphaltic based), and whether the stabilized materials are mixed-in-place or plant-mixed. For a mixed-in-place stabilized base these include stockpiling, aggregate unloading, aggregate spreading and grading, reagent unloading, spreading and grading, moisture application, mixing in place with a pulvimixer, compacting, and surface sealing. For a plant-mixed stabilized base these include stockpiling, aggregate loading and feeding, reagent feeding, water addition, plant mixing, truck loading, truck unloading, spreading and grading, moisture application (if needed), compacting, and surface sealing.

Table 7-7 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in the construction of stabilized bases. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and fugitive dust emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the stabilized base.

Table 7-8 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in the construction of stabilized bases. During the post-construction period, three long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, and surface water quality.

Flowable Fill

Short-term environmental, health, and safety issues associated with the use of flowable fill containing a substitute material may occur during production, storage, transportation, and material placement.

Table 7-9 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in flowable fill mixes. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and fugitive dust emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the fill.

Table 7-10 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in flowable fill mixes. During the post-construction period, three long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, and surface water quality.

Embankment and Fill

Short-term environmental, health, and safety issues associated with the construction of an embankment using a substitute material may occur during, storage, transportation, spreading and grading, and compacting operations.

Table 7-11 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in the construction of an embankment or fill. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and fugitive dust emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the embankment or fill.

Table 7-12 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in the construction of an embankment or fill. During the post-construction period, three long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, and surface water quality.

Landscaping Materials

Short-term environmental, health, and safety issues associated with the use of recycled landscaping material may occur during storage, transportation, spreading and grading, and compacting operations. Table 7-13 provides a description of short-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of substitute materials in the construction of an embankment or fill. The recommended short-term monitoring activities focus on air quality issues as they relate to material handling and fugitive dust emissions.

Long-term environmental, health, and safety issues are primarily associated with the service life of the material.

Table 7-14 provides a description of long-term monitoring activities recommended to assess potential environmental, health, and safety impacts associated with the use of the substitute materials in the construction of an embankment or fill. During the post-construction period, three long-term environmental, health, and safety issues may warrant monitoring: leachate quality, groundwater quality, and surface water quality.

ESTABLISH ACCEPTABLE CRITERIA

During the design and/or approval of the test plan, the decision maker will need to determine the criteria on which an approval or a rejection of the environmental evaluation will be based. Two types of criteria are available for use in such an evaluation. These include local State ambient air, water, and soil standards, or alternatively, specifications or criteria imposed by local jurisdictions (e.g., State environmental agencies). Emissions or discharges from the test section can be compared with these standards, or alternatively, companion control sections of comparable design using only conventional materials be constructed and monitored alongside the test section. A control section provides the means to establish a basis for comparing the performance of the proposed product to that of conventional materials to enable the decision maker to assess whether the new test section results in greater (or less) environmental impact.

EVALUATE FIELD ENVIRONMENTAL, HEALTH, AND SAFETY DATA FOR POSSIBLE APPROVAL

As illustrated in Figure 7-1, to evaluate field demonstration data it is recommended that comparisons to control test sections or appropriate air, water, and land standards, established by the U.S. EPA or State environmental agencies, be made to assess the suitability of the proposed material in the selected application. Chapter 10 information on criteria that can be used in a Stage 3 evaluation.

Statistical comparisons between the material test sections and the control sections or regulatory limits will be required. Examples of the types of statistical comparisons that can be made are identified in Chapter 9.

Table 7-1. Asphalt paving short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, production, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions. Drying operations at a hot mix plant may result in modified particulate, trace metal, or trace organic increased particulate and volatile stack emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from construction material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During plant production operations, the presence of excessive amounts of dust can be a signal that fugitive dusting may be a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile or asphalt pavement containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release from material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments. At a hot mix plant, the stack gas can be monitored for particulates, trace metals, and semi-volatile and volatile emissions using standard sampling trains.

Table 7-2. Asphalt paving long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the asphalt pavement. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing the expected leachate quality generated by both unbound material and the bound asphalt-matrix. Samples of the asphalt pavement material collected during the pavement's service life can be used to assess whether the availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of such samples would normally require a coring rig or power auger to extract the sample.	The presence of any odorous or discolored leachate discharge from the asphalt pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the asphalt pavement. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through or runoff from the asphalt pavement. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any odors or discoloration in observable groundwater in the vicinity of the asphalt pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the asphalt pavement. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Runoff Quality refers to the level of dissolved or particulate matter in runoff resulting from precipitation and runoff from an asphalt pavement. High concentrations of trace metals or organics in the runoff could impact surrounding receptors	To assist in predicting the quality of runoff from a pavement prior to construction, it is recommended that samples of the proposed material be subjected to leaching tests. These tests should characterize expected leachate quality generated by both the	The presence of any odorous or discolored runoff from the asphalt pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if	Runoff samples can be collected by designing and constructing small settling basins to retain runoff for collection or by installing automatic sampling devices to collect runoff flow from drainage piping or ditches. Runoff

Table 7-2. Asphalt paving long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
such as surface waters, groundwaters, and soils. If the test pavement is not used in a wearing course, then runoff collection and testing from an asphalt pavement may not be required.	unbound material and the bound asphalt-matrix material. Leachate test results can be used to represent estimates of expected runoff quality.	the source is unknown.	samples should be tested for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate, runoff, or fine particulate releases (abrasion) from an asphalt pavement. Sampling and testing of surface water receptors would, in most cases, be considered where direct measurements of leachate or runoff quality are not feasible.		The presence of any odorous or discolored surface waters downstream of the asphalt pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Depending on the size and duration of the monitoring effort, the collection of both water column and bottom sediments may be warranted. The latter would be sampled if settleable particulates may be migrating toward the water course. Subsurface samples are typically collected using coring equipment or small dredge buckets. Surface water quality should be tested for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Soil Quality refers to the soil receptor that could be impacted by potential leachate, runoff, or fine particulate releases from an asphalt pavement. Sampling and testing of soil receptors would, in most cases, be considered where direct measurements of leachate or groundwater or dust emissions are not feasible.			Soils beneath the asphalt pavement can be collected using a boring rig that can drill through the asphalt pavement and drive sampling devices (e.g., split spoon samplers) into the soil beneath the asphalt pavement. Soils adjacent to the pavement can be collected using scoops or soil coring equipment. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that are present in the substitute material.

Table 7-3. Portland cement concrete short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, production, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from construction material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During plant production operations, the presence of excessive amounts of dust can be a signal that fugitive dusting is a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile or concrete pavement containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release from material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments.

Table 7-4. Portland cement concrete long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the Portland cement concrete pavement. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing the expected leachate quality generated by both unbound material and the bound concrete-matrix. Samples of the concrete pavement material collected during the pavement's service life can be used to assess whether the leaching availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of such samples would normally require a coring rig or power auger to extract the sample.	The presence of any odorous or discolored leachate discharge from the concrete pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the concrete pavement. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through the concrete or runoff from the concrete pavement. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any odors or discoloration observable in groundwater in the vicinity of the concrete pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the portland cement concrete pavement. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Runoff Quality refers to the level of dissolved or particulate matter in runoff resulting from precipitation and runoff from a concrete pavement. High concentrations of trace metals or organics in the runoff	To assist in predicting runoff quality from a pavement prior to construction, it is recommended that samples of the proposed material be subjected to leaching tests. These tests should characterize expected	The presence of any odorous or discolored runoff from the concrete pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate	Runoff samples can be collected by designing and constructing small settling basins to retain runoff for collection or by installing automatic sampling devices to collect runoff flow

Table 7-4. Portland cement concrete long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
could impact surrounding receptors such as surface waters and soils. If the test pavement is not used in a wearing course, then runoff collection and testing from a concrete pavement may not be required. However, if the concrete pavement is exposed to rainfall, then runoff monitoring would, in most cases, be warranted.	leachate quality generated by both the unbound material and the bound concrete-matrix material. Leachate test results can be used to represent estimates of expected runoff quality.	additional sampling and analysis if the source is unknown.	from drainage piping or ditches. Runoff samples should also be tested for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate, runoff, or fine particulate releases from the concrete pavement. Sampling and testing of surface water receptors would, in most cases, only be considered where direct measurements of leachate or runoff quality are not feasible or if direct measurements indicate substantive contaminant releases.		The presence of any unusual or discolored liquid discharge or odor in the vicinity of the concrete pavement may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Depending on the size and duration of the monitoring effort, the collection of both water column and bottom sediments may be warranted. The latter would be sampled if settleable particulates may be migrating toward the water course. Subsurface samples are typically collected using coring equipment or small dredge buckets. Surface water quality should be tested for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Soil Quality refers to the soil receptor that could be impacted by potential leachate, runoff, or fine particulate releases from a concrete pavement. Sampling and testing of soil receptors would, in most cases, only be considered where direct measurements of leachate or groundwater or dust emissions are not feasible or if direct measurements indicate substantive contaminant releases.			Soils beneath the concrete pavement can be collected using a boring rig that can drill through the concrete pavement and drive sampling devices (e.g., split spoon samplers) into the soil beneath the concrete pavement. Soils adjacent to the pavement can be collected using scoops or soil coring equipment. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that

Table 7-4. Portland cement concrete long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
			are present in the substitute material.

Table 7-5. Granular base short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, handling, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from construction material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During construction operations, the presence of excessive amounts of dust can be a signal that fugitive dusting is a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release from construction and material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments.

Table 7-6. Granular base long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the granular base. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction, it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing the expected leachate quality of the unbound material. Samples of the granular base material collected during the base's service life can be used to assess whether the leaching availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of such samples would normally require a coring rig or power auger to extract the sample from under the pavement.	The presence of any odorous or discolored leachate discharge from the granular base may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the granular base. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through the concrete or runoff from the granular base. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any odors or discoloration in observable groundwater in the vicinity of the granular base may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the granular base. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate from the granular base. Sampling and testing of surface water receptors would, in most cases, only be considered where direct measurements of leachate or runoff		The presence of any odorous or discolored surface waters downstream of the granular base may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Water column samples can be collected upgradient and downgradient of the granular base to assess potential impacts. Water column samples should be tested for those chemical constituents (trace metals and trace organics) that are present in significant

Table 7-6. Granular base long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
quality are not feasible or if direct measurements indicate substantive contaminant releases.			quantities in the substitute material.
Soil Quality refers to the soil receptor that could be impacted by potential leachate percolating through the granular base. Sampling and testing of soil receptors would, in most cases, only be considered where direct measurements of leachate or groundwater or dust emissions are not feasible or if direct measurements indicate substantive contaminant releases.			Soils beneath the granular base can be collected using a boring rig that can drill through the granular base and drive sampling devices (e.g., split spoon samplers) into the soil beneath the granular base. Soils adjacent to the granular base can be collected using scoops or soil coring equipment. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that are present in the substitute material.

Table 7-7. Stabilized base short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, handling, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from construction material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During construction operations, the presence of excessive amounts of dust can be a signal that fugitive dusting is a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release from construction and material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments.

Table 7-8. Stabilized base long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the stabilized base. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction, it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing the expected leachate quality of the unbound and bound stabilized-base matrix material. Samples of the stabilized base material collected during the base's service life can be used to assess whether the leaching availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of such samples would normally require a coring rig or a power auger to extract the sample from under the pavement.	The presence of any odors or discoloration in observable groundwater in the vicinity of the stabilized base may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the stabilized base. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through the concrete or runoff from the granular base. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any unusual or discolored liquid discharge or odor in the vicinity of the granular base may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the stabilized base. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate from the stabilized base. Sampling and testing of surface water receptors would, in most cases, only be considered where direct		The presence of any odorous or discolored surface waters downstream of the stabilized base may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling	Water column samples can be collected upgradient and downgradient of the stabilized base to assess potential impacts. Water column samples should be tested for those chemical constituents (trace metals and trace organics)

Table 7-8. Stabilized base long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
measurements of leachate or runoff quality are not feasible or if direct measurements indicate substantive contaminant releases.		and analysis if the source is unknown.	that are present in significant quantities in the substitute material.
Soil Quality refers to the soil receptor that could be impacted by potential leachate percolating through the stabilized base. Sampling and testing of soil receptors would, in most cases, only be considered where direct measurements of leachate or groundwater or dust emissions are not feasible or if direct measurements indicate substantive contaminant releases.			Soils beneath the stabilized base can be collected using a boring rig that can drill through the stabilized base and drive sampling devices (e.g., split spoon samplers) into the soil beneath the stabilized base. Soils adjacent to the stabilized base can be collected using scoops or soil coring equipment. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that are present in the substitute material.

Table 7-9. Flowable fill short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, production, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from construction material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During plant production operations, the presence of excessive amounts of dust can be a signal that fugitive dusting is a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release from material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments.

Table 7-10. Flowable fill long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the in-place fill. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing the expected leachate quality generated by both unbound material and the bound flowable fill-matrix. Samples of the fill material collected during the fill's service life can be used to assess whether the leaching availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of such samples would normally require a hand or power auger.	The presence of any odorous or discolored leachate discharge from the in-place fill may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the fill. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through the in-place fill from the concrete pavement. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any odors or discoloration in observable groundwater in the vicinity of the in-place fill may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the flowable fill. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate released from the fill material. Sampling and testing of surface water receptors would, in most cases, only be considered where direct measurements of leachate quality are		The presence of any odorous or discolored surface waters downstream of the in-place fill may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Water column samples can be collected upgradient and downgradient of the granular base to assess potential impacts. Water column samples should be tested for those chemical constituents (trace metals and trace organics) that are present in

Table 7-10. Flowable fill long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
not feasible or if direct measurements indicate substantive contaminant releases.			significant quantities in the substitute material.
Soil Quality refers to the soil receptor that could be impacted by potential leachate released from the fill. Sampling and testing of soil receptors would, in most cases, only be considered where direct measurements of leachate or groundwater or dust emissions are not feasible or if direct measurements indicate substantive contaminant releases.			Soils beneath the fill area can be collected using a boring rig and split spoon samplers. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that are present in the substitute material.

Table 7-11. Embankment and fill short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, handling, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from construction material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During construction operations, the presence of excessive amounts of dust can be a signal that fugitive dusting is a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release due to construction and material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments.

Table 7-12. Embankment and fill long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the granular base. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction, it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing the expected leachate quality of the unbound material. Samples of the embankment or fill material during the structure's service life can be collected to assess whether the leaching availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of samples for such testing would normally require a coring rig, power auger, or hand auger to extract the sample.	The presence of any odorous or discolored leachate discharge from the embankment or fill may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the granular base. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through the embankment or fill. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any odors or discoloration in observable groundwater in the vicinity of the embankment or fill may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the embankment or fill. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate from the embankment or fill. Sampling and testing of surface water receptors		The presence of any odorous or discolored surface water downstream of the embankment or fill may be indicative of the presence of potentially detrimental constituents	Water column samples can be collected upgradient and downgradient of the embankment or fill to assess potential impacts. Water column samples should be

Table 7-12. Embankment and fill long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
would, in most cases, only be considered where direct measurements of leachate or runoff quality are not feasible or if direct measurements indicate substantive contaminant releases.		within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	tested for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Soil Quality refers to the soil receptor that could be impacted by potential leachate percolating through the embankment or fill. Sampling and testing of soil receptors would, in most cases, only be considered where direct measurements of leachate or groundwater or dust emissions are not feasible or if direct measurements indicate substantive contaminant releases.			Soils beneath the embankment or fill can be collected using a boring rig that can drill through the granular base and drive sampling devices (e.g., split spoon samplers) into the soil beneath the structure. Soils adjacent to the embankment or fill can be collected using scoops or soil coring equipment. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that are present in the substitute material.

Table 7-13. Landscaping material short-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Air Quality refers to the ambient air receptor in the vicinity of the material storage, handling, and construction process. Truck loading, unloading, and material handling operations have the potential to release fugitive dust and volatile emissions.	Prior to construction, it is recommended that grab or composite samples of the material be collected, directly from landscaping material stockpiles, and analyzed to verify that the environmental properties of the materials quantified during the planning process are similar to those of the construction material. The extent of the preconstruction testing that will be needed to verify the design testing will depend on the homogeneity of the source material. Depending on the type of material, characterization testing could include inorganic and organic composition, and moisture and fines content.	During construction operations, the presence of excessive amounts of dust can be a signal that fugitive dusting is a problem and air monitoring activities (if not planned) may be warranted. The presence of any unusual or objectionable odors associated with a stockpile containing a substitute material may be indicative of the presence of organic or volatile constituents within the subject material. Such observations may necessitate additional analysis of the source material or the volatile components to determine whether these odors are aesthetic or health and safety concerns.	The level of dust release from construction and material handling operations can be assessed by using high-volume samplers placed within or adjacent to the perimeter of the work site. Monitoring of the worker environment can be undertaken using personal air samplers worn by workers or placed in strategically selected work area locations. Volatile constituents can be measured by use of a sorbent filter apparatus or portable direct reading instruments.

Table 7-14. Landscaping material long-term field monitoring recommendations.

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
Leachate Quality refers to the level of dissolved or particulate matter in liquid percolating through the granular base. High concentrations of trace metals or organics in the leachate could adversely impact groundwaters and surface waters.	Prior to construction, it is recommended that samples of the proposed material be subjected to leaching tests to assist in characterizing its expected leachate quality. Samples of the landscaping material during the structure's service life can be collected to assess whether the leaching availability (mobility of trace metals and organics within the matrix) might be increasing or decreasing with both long-term curing and exposure to the environment; collection of samples for such testing would normally require a coring rig, power auger, or hand auger to extract the sample.	The presence of any odorous or discolored leachate discharge from the landscaping material may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Leachate collection can be conducted by installing, during construction, lysimeters, leachate collection pans, or sumps that could be used to catch percolating or migrating liquid through the granular base. Leachate samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the proposed materials.
Groundwater Quality refers to the groundwater receptor that could be impacted by leachate percolating through the embankment or fill. Sampling of groundwater would in most cases be considered if leachate samples cannot be adequately collected for testing.		The presence of any odors or discoloration in observable groundwater in the vicinity of the landscaping material may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is unknown.	Groundwater can be monitored by installing monitoring wells upgradient and downgradient of the landscaping material. Upgradient wells can provide a control sample or baseline groundwater sample. Groundwater samples collected should be analyzed for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.
Surface Water Quality refers to the surface water receptor that could be impacted by potential leachate from the embankment or fill. Sampling and testing of surface water receptors would, in most cases, only be considered where direct measurements of		The presence of any odorous or discolored surface water downstream of the landscaping material may be indicative of the presence of potentially detrimental constituents within the subject material, and would necessitate additional sampling and analysis if the source is	Water column samples can be collected upgradient and downgradient of the landscaping material to assess potential impacts. Water column samples should be tested for those chemical constituents (trace metals and trace organics) that are present in significant quantities in the substitute material.

Table 7-14. Landscaping material long-term field monitoring recommendations (continued).

Env., Health & Safety Issues	Material Sampling and Analysis	Visual Observations	In-Place Indicators
leachate or runoff quality are not feasible or if direct measurements indicate substantive contaminant releases.		unknown.	
Soil Quality refers to the soil receptor that could be impacted by potential leachate percolating through the embankment or fill. Sampling and testing of soil receptors would, in most cases, only be considered where direct measurements of leachate or groundwater or dust emissions are not feasible or if direct measurements indicate substantive contaminant releases.			Soils beneath the landscaping material can be collected using a boring rig that can drill through the granular base and drive sampling devices (e.g., split spoon samplers) into the soil beneath the structure. Soils adjacent to the embankment or fill can be collected using scoops or soil coring equipment. Collected soil samples should be tested for those chemical properties (trace metal content and organics) that are present in the substitute material.

INTRODUCTION

Chapter 8 presents an example of the evaluation process. It provides a step-by-step application of the framework process outlined in Figure 8-1 and the evaluation checklists introduced in this document. It is assumed in this example that an applicant submits an application to a State DOT and that the DOT initiates a joint review of the subject application with the State environmental agency. Together, the two agencies constitute the decision maker or evaluator.

STEP 1 – SELECT MATERIAL/APPLICATION

The applicant submits an application to the State DOT to use an industrial slag as an aggregate substitute in hot mix asphalt base courses.

STEP 2 – DEFINE AND EVALUATE ISSUES

The State DOT evaluator notifies the State environmental regulatory agency counterpart that an application has been submitted. A meeting is set up where the applicant is requested to provide responses to the issues evaluation checklist questions outlined in Chapter 2, Purpose and Methodology.

- Historical experience (Table 2-2).
- Engineering issues (Table 2-3).
- Environmental issues (Table 2-4).
- Implementation issues (Table 2-5).
- Recycling issues (Table 2-6).
- Economic issues (Table 2-7).

The applicant submits the completed issues evaluation checklist tables, which are presented in Tables 8-1 through 8-6. A summary of the results of the issues evaluation checklist analysis is presented in Table 8-7. The reviewing agencies determine if any significant issues warrant modification or dismissal of the permit request; however, the absence of adequate environmental data means that, at a minimum, a Stage 2 environmental and perhaps health and safety step will be necessary. A Stage 1 screen is initiated.

STEP 3 – STAGE 1 SCREENING EVALUATION

The Stage 1 screen is undertaken in accordance with the checklist outlined in Chapter 3, Screening.

- Engineering properties (Table 3-1).
- Environmental properties (Table 3-2).

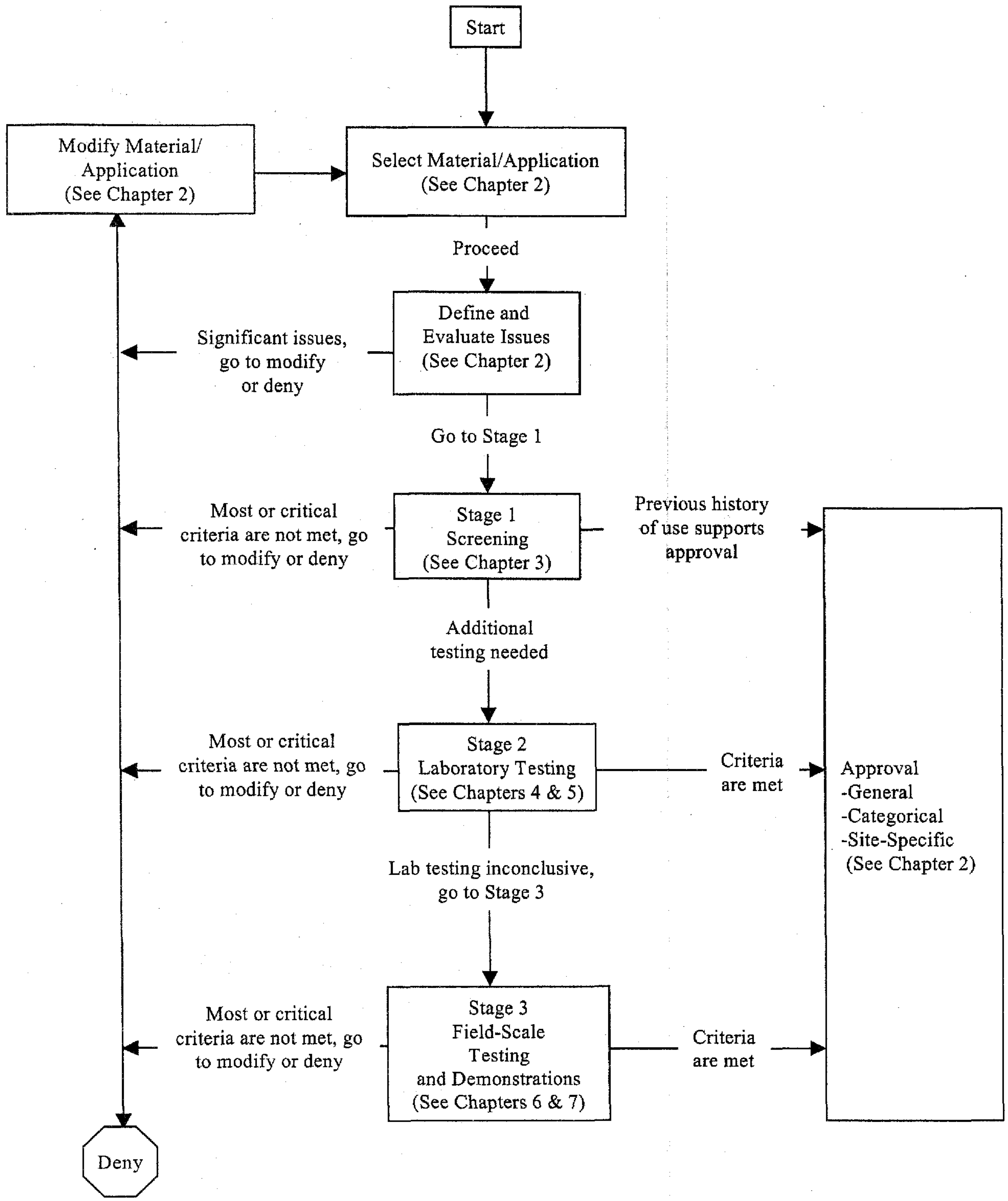

Figure 8-1. Evaluation framework flow process.

Table 8-1. History and previous experience questions.

General Area	General Questions	
History	1. Has the recycled material been used before? If so, identify uses.	Y ☐ N ☒
	2. Is information available about the source of the recycled material? If so, collect it.	Y ☒ N ☐
	3. Has this recycled material been previously used? If so, identify applications.	Y ☐ N ☒
	4. Has this recycled material been used in geographically diverse locations? If so, identify locations.	Y ☐ N ☒
	5. Has it been used previously in a similar application? If so, identify location.	Y ☐ N ☒
	6. Has this recycled material been used in other jurisdictions? If so, identify jurisdiction.	Y ☐ N ☒
	7. Have other jurisdictions granted use? If so, identify jurisdictional province.	Y ☐ N ☒
Previous Experience	1. Is information available about important prior experiences (previous use, prior objections, similarity with other materials)? If so, collect the information.	Y ☒ N ☐
	2. Are there experts available to discuss prior experiences? This can include regulators, scientists, practitioners, waste generators, associations. If so, contact the experts.	Y ☐ N ☒
	3. Is there any published literature about prior experiences? If so, obtain the information.	Y ☐ N ☒

Table 8-2. Engineering and materials properties questions.

General Area	General Questions	
Engineering	1. Is information available about the engineering properties of the recycled material? This could include information about gradation, bulk density, durability, and compaction data. If so, collect the pertinent information.	Y ☒ N ☐
	2. Is the recycled material appropriately characterized with respect to time-dependent engineering properties? This could include time-dependent variation in gradation, bulk density, durability, and compaction. If so, collect the pertinent information.	Y ☒ N ☐
	3. For the proposed application, are there appropriate engineering criteria for the product? This could include durability, grain size, and compaction requirements. If so, collect the pertinent criteria.	Y ☒ N ☐
	4. Is engineering information available about important prior experiences (previous use, prior performance criteria, similarity with other materials)? If so, assemble the pertinent information.	Y ☒ N ☐
Materials Properties	1. Is information available about the materials properties of the recycled material? This could include information about loss on ignition, mineralogy, and pozzolanic activity of the waste material. If so, summarize the data.	Y ☒ N ☐
	2. Is the recycled material appropriately characterized with respect to time-dependent materials properties? If so, summarize the data.	Y ☒ N ☐
	3. For the proposed application, are there appropriate materials properties criteria for the product? If so, identify the criteria.	Y ☒ N ☐

Table 8-3. Environmental, health, and safety (EHS) properties questions.

General Area	General Questions	
Environmental	1. Is information available about the environmental properties of the recycled material? This could include information about total elemental composition, total available element composition, and volatile and semi-volatile organics composition data. If so, collect the pertinent information.	Y ☐ N ☒
	2. Is the recycled material appropriately characterized with respect to time-dependent environmental properties? This could include time-dependent variation in total elemental composition, total available element composition, and volatile and semi-volatile organics composition. If so, collect the pertinent information.	Y ☐ N ☒
	3. For the proposed application, are there appropriate environmental criteria for the product? This could include leaching data, total content data, particle size, etc. If so, collect the pertinent criteria.	Y ☐ N ☒
	4. Is environmental information available about important prior experiences (previous use, prior performance criteria, similarity with other materials)? If so, assemble the pertinent information.	Y ☐ N ☒
	5. Have there been any environmental assessments undertaken relative to the use of the proposed material. If so, summarize the information.	Y ☐ N ☒
Public Health	1. Are there any Materials Safety Data sheets (MSDS) for the recycled materials? If so, collect the sheets.	Y ☐ N ☒
	2. Have there been health risk assessment (HRA) undertaken relative to the proposed use of the material? If so, summarize the information.	Y ☐ N ☒
Safety	1. Have there been prior OSHA issues for generation, processing, storage, and use in previous efforts? If so, summarize the information.	Y ☐ N ☒

Table 8-4. Implementation issue questions.

General Area	General Questions	
Implementation	1. Are there any apparent political constraints? If so, describe them.	Y☐ N☐ U☒
	2. Are there any apparent regulatory constraints? If so, describe them.	Y☐ N☐ U☒
	3. Are there any apparent public acceptability constraints? If so, describe them.	Y☐ N☐ U☒

Table 8-5. Recycling issue questions.

General Area	General Questions	
Recycling	1. Are there likely recycling or life-cycle issues? If so, identify them.	Y☐ N☐ U☒
	2. Has the recycled material or its application been reused within other areas of the highway environment? If so, identify them.	Y☐ N☒ U☐

Table 8-6. Economic issue questions.

General Area	General Questions	
Economic	1. Are there any apparent economic constraints? If so, identify them.	Y☐ N☒ U☐

Table 8-7. Industrial slag as an aggregate substitute in an asphalt base course issue evaluation.

Area of Evaluation	Identified Issue
Historical Experience	The industrial slag from the applicant's facility has not been previously used in any application. Similar materials from other facilities have been used as an aggregate substitute material in asphalt pavements.
Engineering Issues	The applicant has gathered a significant amount of relevant engineering and material property data.
Environmental Issues	The applicant has inadequate environmental data.
Implementation Issues	No problematic issues were identified.
Recycling Issues	No problematic issues were identified.
Economic Issues	No problematic issues were identified.

- Recycling (Table 3-3).
- Implementation (Table 3-4).
- Economics (Table 3-5).

The applicant submits supporting data to assist the evaluators in completing Tables 3-1 through 3-5, which are presented in Tables 8-8 through 8-12.

Stage 1 Engineering Properties Screen

The applicant is requested to provide data to demonstrate statistically that the engineering data submitted for the slag material will be consistent with time and that the engineering properties of the slag are statistically similar to reference materials (similar material that the applicant claimed has been successfully used in the past). Table 8-8 outlines the Stage 1 engineering evaluation. Chapter 9 provides examples on how to statistically analyze measured properties of a material and how to compare the properties with the desired specifications.

Based on the information provided, the decision maker determines that the engineering properties of the slag will be consistent throughout the year and that the properties of the slag are statistically similar to that of the reference material.

Stage 1 Environmental, Health, and Safety Screen

The applicant has inadequate environmental data for the industrial slag. Table 8-9 outlines the Stage 1 environmental evaluation. A Stage 2 laboratory analysis will be required.

Table 8-8. Stage 1 engineering screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	
Material Production	Determine whether the proposed material is generated from the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☒ N☐ U☐
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to that of the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☒ N☐ U☐
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the engineering properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☒ N☐ U☐
Engineering Properties	Assess whether there are sufficient data to compare the engineering properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate engineering property data available for both the proposed and reference materials, and are the data reliable?	Y☒ N☐ U☐
		2. Can it be determined that the proposed and reference materials have statistically similar engineering properties that are in conformance with the specifications of the proposed application, and are they comparable?	Y☒ N☐ U☐
Field Performance	Determine whether the reported historical data for the reference material provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	Y☒ N☐ U☐
		2. Are there personal contacts (engineers with experience) available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	Y☒ N☐ U☐
		3. Is the historical performance data of the material sufficient to warrant a Stage 1 approval?	Y☒ N☐ U☐

1. Y = Yes, N = No, U = Unknown

Table 8-9. Stage 1 environmental, health, and safety screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	
Material Source	Determine whether the proposed material is generated from the same process or operation as the reference material.	1. Will the quality of feedstock materials to be used in the production or generation of the proposed material be sufficiently similar to that used to produce or generate the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☐ N☐ U☒
		2. Will the operating conditions associated with the production or generation of the proposed material be sufficiently similar to that of the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☐ N☐ U☒
		3. Will the post-production operations (e.g., material processing, handling, and storage) associated with the production or generation of the proposed material be sufficiently similar to the reference material so that the environmental properties of the proposed material will not be significantly impacted and will still be comparable to the reference material?	Y☐ N☐ U☒
Environmental Properties	Assess whether there are sufficient data to compare the environmental properties of the proposed material and reference material, and whether the respective properties are sufficiently similar to approve the proposed material for use.	1. Are appropriate environmental property data available for both the proposed and reference materials, and are the data reliable?	Y☐ N☒ U☐
		2. Can it be determined that the proposed and reference materials have statistically similar environmental properties that are in conformance with the specifications of the proposed application, and are they comparable?	Y☐ N☒ U☐
Field Performance	Determine whether the reported historical data provided give reasonable assurance that the proposed material will provide satisfactory performance in the intended application.	1. Is there a sufficient and reliable historical performance record available?	Y☐ N☒ U☐
		2. Are there personal contacts (regulators or scientists with experience) available with whom to review the results of the historical performance data, and have the above-referenced contacts provided positive feedback regarding the application?	Y☐ N☒ U☐
		3. Were there any specific problems or difficulties reported, and were the reported problems satisfactorily addressed in previous investigations to warrant a Stage 1 approval?	Y☐ N☒ U☐

1. Y = Yes, N = No, U = Unknown

Table 8-10. Stage 1 recycling screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	
Engineering Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the engineering quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the production process during a post-service life application?	Y☐ N☒ U☐
		2. Could the proposed material properties be altered during either its service life or post-service life processing to such an extent that it could significantly impact the properties of the secondary material?	Y☐ N☒ U☐
Environmental Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the environmental quality of the product if used in a secondary application at the completion of its useful service life?	1. Could the proposed material adversely impact the environment (air, water, or soil quality) during post-service life processing if introduced into a secondary application?	Y☐ N☐ U☒
		2. Could the proposed material adversely impact the environment (air, water, or soil quality) during its post-service life use if introduced into a secondary application?	Y☐ N☐ U☒
		3. Could the proposed material adversely impact the environment (air, water, or soil quality) if disposed of as construction and demolition debris after its initial service life?	Y☐ N☐ U☒
Worker Health and Safety Acceptability	If the proposed material is incorporated into the engineered product, could it significantly impact the worker health and safety properties of the product if used in a secondary application at the completion of its useful service life?	1. Could harmful fugitive dust or volatile gaseous emissions resulting from the use of the proposed material impact worker health or safety during post-service life processing or construction activities?	Y☐ N☐ U☒
		2. Could the use of the proposed material create a hazard to the physical safety of workers during post-service life processing or construction activities?	Y☐ N☐ U☒

1. Y = Yes, N = No, U = Unknown

Table 8-11. Stage 1 implementation screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	H	M	L
Institutional Acceptability	Consider the probability that the regulatory community will approve and the technical community will accept and utilize the material in the proposed application.	1. Rate the degree of difficulty that can be anticipated in obtaining approval to incorporate the material-application match into existing construction specifications.	☐	☒	☐
		2. Rate the degree of difficulty that can be anticipated prior to the receipt of environmental approvals from regulatory agencies.	☐	☒	☐
		3. Rate the degree of reluctance that engineers might have in specifying the material in the proposed application.	☐	☒	☐
		4. Rate the degree of reluctance that contractors might have in utilizing the material in the proposed applications.	☐	☐	☒
Political Acceptability	Consider the degree to which public officials will support or impede the proposed application.	1. Rate the degree to which political opposition could impede the application.	☐	☒	☐
Public Acceptability	Assess the degree to which the public will accept the proposed material-application strategy.	1. Rate the degree to which the public opposition due to perceived environmental, health, safety, or economic impacts could impede the application.	☐	☒	☐

1. H = High, M = Medium, L = Low

Table 8-12. Stage 1 economic screening checklist.

Parameter	Test Method	Evaluation Criteria[1]	Y	N
Material Cost	$C_{DP} = P_{RM} + C_{PR} + C_{ST} + C_{LD} + C_{TR} + P$ (1) where C_{DP} = Delivered price of proposed material, P_{RM} = Price of the raw proposed material (F.O.B.), C_{PR} = Cost of processing the material, C_{ST} = Cost of stockpiling the material, C_{LD} = Cost of loading the material, C_{TR} = Cost of transporting the material, and P = Profit.	Is $C_{DP} \leq C_{DC}$? where C_{DC} = Delivered price of conventional material	☒	☐
Installation Cost	$C_{IP} = C_{DR} + C_{DP} + C_C + T_{RP}$ (2) where C_{IP} = Cost of installation using the proposed material, C_{DP} = Delivered price of proposed material (see Eq. 1) C_{DR} = Cost for design of application with the recovered material, C_C = Cost for construction with the recovered material, and T_{RP} = Cost of testing and inspection for the proposed application.	Is $C_{IP} \leq C_{IC}$? where C_{IC} = Cost of installation using conventional materials	☒	☐
Life-Cycle Cost	$A_{CP} = C_I \cdot CRF(i,n) + C_{AM}$ (3) where A_{CP} = Annual life-cycle cost using proposed material, C_{IP} = Cost of installation using proposed material (see Eq. 2) CRF(i,n) = The capital recovery factor with an interest rate of i percent and an expected service life of n years, and C_{AM} = Annual maintenance cost.	Is $A_{CP} \leq A_{CC}$? where A_{CC} = Annual cost using conventional materials	☒	☐

1. Y = Yes, N = No

Stage 1 Recycling Evaluation

The decision maker and applicant define the likely reuses of the recycled base course, which will contain the industrial slag. The potential engineering and environmental issues are evaluated for each reuse scenario. Table 8-10 outlines the Stage 1 recycling evaluation. Although no engineering issues were identified, the absence of adequate environmental data means that recycling from an environmental perspective could not be fully assessed.

Stage 1 Implementation Evaluation

The implementation screen defines potential technical, public, and political issues that may arise from the proposed use of the industrial slag. Table 8-11 outlines the Stage 1 implementation evaluation. The absence of environmental data at the current stage of the evaluation limits the ability of the decision maker to adequately assess this issue.

Stage 1 Economic Evaluation

The results of the economic screen, presented in Table 8-12, suggest that a significant economic incentive exists to utilize the material.

A summary of the results of the Stage 1 screening is presented in Table 8-13. The reviewing agencies determine that the submitted engineering data are adequate.

Table 8-13. Stage 1 screening results.

Evaluation Area	Evaluation Results
Engineering	The engineering evaluation did not identify any problematic issues. The industrial slag meets all required engineering criteria, and the production process meets required quality control criteria. No further engineering evaluation is required.
Environmental, Health, and Safety	Due to the lack of data, a Stage 1 evaluation could not be performed. A Stage 2 analysis is required.
Recycling	Due to the absence of environmental data, analysis of recycling issues could not be fully assessed.
Implementation	Due to the absence of environmental data, analysis of implementation issues could not be fully assessed.
Economic	It is economically practical to utilize the slag in the proposed application.

STEP 4 – STAGE 2 LABORATORY TESTING

On the basis of the results of the Stage 1 screen, the decision maker prepares an environmental test plan and criteria for evaluation. Table 8-14 provides an outline of the Stage 2 environmental test plan, criteria, and test results. The sequence of environmental tests presented in Table 8-14 is consistent with the environmental properties and tests outlined in Chapter 5, Table 5-2 for aggregate substitutes in bound applications.

The applicant is requested to undertake regulatory tests, inorganic composition tests, inorganic leaching tests, acid-base leach tests, and product organic leach tests.

The results of these tests indicate that the slag is nonhazardous, but contains concentrations of arsenic and chromium that were one order of magnitude higher than soil reference guidelines (cleanup guidelines). Leachate concentrations from distilled water leaching tests for inorganic constituents were all less than drinking water standards but the 90 percent confidence limit for arsenic exceeded the drinking water criterion. Acid-base leaching tests revealed higher arsenic concentrations in higher acid (low pH) solutions. Product testing was undertaken by preparing a design mix where the slag was incorporated into the hot mix product. The product was subjected to a distilled water leaching test and to Toxicity Characteristic Leaching Procedure (TCLP) testing protocols to assess the potential for leaching of the product in an aggressive leaching environment. All leachate concentrations were found to be below drinking water criteria.

APPROVAL PROCESS

Upon review of the Stage 2 environmental test results, the decision maker determines that there is minimal potential risk to the environment if the slag is used in the proposed application. Nonetheless, to ensure environmental protection, the decision maker issues a categorical approval for the proposed application, which provides a number of test requirements and application limitations. The decision requires the following:

1. The slag may be used in a hot mix base course at levels not to exceed 10 percent by weight of aggregate.

2. A monitoring program is established to test for levels of arsenic and chromium in the slag product and a limiting level (one order of magnitude above the soil guidelines) is established). Any concentration above such levels would result in material rejection.

Table 8-14. Stage 2 environmental testing results.

Environmental Property	Criteria	Results
Regulatory Testing of Aggregate Substitute	40 CFR, Part 261.21 40 CFR, Part 261.22 40 CFR, Part 261.23 40 CFR, Part 261.24	Nonignitable Noncorrosive Nonreactive Nontoxic
Inorganic Composition of Aggregate Substitute	Soil reference guidelines	The concentrations of arsenic and chromium were approximately one order of magnitude above the soil reference standards.
Organic Composition of Aggregate Substitute	-	Not required by decision maker since material has undergone a high temperature process.
Particle Size of Aggregate Substitute	-	Not required by decision maker since material is a glassy substance and <1% of the material passes a No. 200 sieve. Fugitive dust emissions are not expected.
Mineralogical Composition of Aggregate Substitute	-	Not required by decision maker because the material has a low dusting potential and a low crystalline silica content.
Inorganic Leaching of Aggregate Substitute	USEPA drinking water standards	A distilled water leaching test was used to determine the inorganic leaching properties of the industrial slag. All leachate concentrations were below drinking water criteria, but the upper 90 percent confidence limit for arsenic (As) exceeds the criteria. A sample statistical calculation is presented in Table 8-15.
Organic Leaching of Aggregate Substitute	-	Not required by decision maker since material has undergone a high temperature process.
Acid-Base Behavior of Aggregate Substitute	-	Results indicate increased leaching of arsenic under acidic conditions.
Product Inorganic Leaching	USEPA drinking water standards	Product inorganic leaching was determined using a distilled water leaching test and the TCLP protocol on crushed product containing the industrial slag. All leachate concentrations were below drinking water criteria.
Product Organic Leaching	-	Not required by decision maker since material has undergone a high temperature process.
Product Abrasion	-	Not required by decision maker since material will be in binder course.
Product - Volatile Emissions	-	Not required by decision maker since material has undergone a high temperature process.

Table 8-15. Stage 2 environmental testing sample statistical calculation.

Sample Arsenic Concentrations (µg/L): 38, 55, 51, 39, 42
Arsenic Drinking Water Criteria (µg/L): 50
Average Concentration (µg/L): 45
Standard Deviation: 7.58
N: 5
t: 2.132

The UCL can be calculated using a t statistic at $\alpha = 0.05$ for n-1 degrees of freedom (4), which is 2.132 (from Chapter 9, Table 9-1).

$$UCL = 45 + 2.132\ (7.58/(5)^{1/2})$$

$$UCL = 52.2$$

Here, the UCL of 52.2 exceeds the criteria of 50 and the material is deemed to exceed the criteria even though the average is 45.

STATISTICS

STATISTICAL NOMENCLATURE

The table below presents a definition of common symbols and terms used in statistical analysis. The reader should refer to the references listed in the Introduction section below for a more detailed discussion of the symbols and terms presented below.

Statistical Symbol	Name	Definition
–	Population	A set of units representing all units in a group of interest to the sample collector
–	Sample	A measured subset of units from the population of interest
μ	Population Mean	The sum of measurements in a population divided by the number of elements in the population (N)
σ^2	Population Variance	Average of the square of the deviations of the measurements about the mean μ
σ	Population Standard Deviation	The positive square root of the variance
N	Number	Number of elements in a population
$\bar{X}$	Sample Mean	The sum of measurements in a sample divided by the number of elements in the sample (n)
s^2	Sample Variance	The sum of the squared deviations of the measurements about their mean $\bar{X}$ divided by (n-1)
s	Sample Standard Deviation	The positive square root of the variance
n	Number	Number of elements in a sample
n-1	Degrees of Freedom	Number of elements in a sample minus 1
α	Alpha	The probability of rejecting the null hypothesis when it is true

INTRODUCTION TO STATISTICAL ISSUES

The following are the basic statistical questions that the applicant and decision maker face when an applicant submits supporting information to obtain approval for use of a recycled material in a construction application:

- Are the data sufficiently representative and normally distributed?
- Do the submitted data for a recycled material meet a specification or limit?
- Are the submitted data similar to historic data?
- For time-dependent recycled material generation or production data, what are the quality control measures that describe the data?
- For time-dependent recycled material generation or production data, are there trends in the data that suggest the data are changing with respect to changes in plant operations, processing operations, or other time-based factors?

These statistical issues are the most likely ones that the applicant and decision maker will face; others may also develop. The following references contain useful information:

- McCuen, R.H. (1985) *Statistical Methods for Engineers*, Prentice-Hall, Englewood Cliffs, New Jersey.
- Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*, van Norstrand Reinhold, New York.
- Berthouex, P.M. and Brown, L.C. (1994) *Statistics for Environmental Engineers*, Lewis Publishers, Boca Raton, Florida.
- McBean, E.A. and Rovers, F.A. (1998) *Statistical Procedures for Analysis of Environmental Monitoring Data & Risk Assessment*, Prentice Hall, Upper Saddle River, New Jersey.
- Natrella, M.G. (1963) *Experimental Statistics*, National Bureau of Standards. Handbook 91, U.S. Government Printing Office, Washington, D.C.
- Hays, W.L. (1994) *Statistics,* Harcourt Brace College Publishers, 5th Edition.

ARE THE DATA HIGH QUALITY, SUFFICIENTLY REPRESENTATIVE, AND NORMALLY DISTRIBUTED?

Two questions frequently raised are: (1) Have sufficiently high-quality data been submitted? and (2) Are the data normally distributed?

High-Quality Data

In the case of data generation for use by decision makers, the applicant should incorporate the following elements to produce high quality data: (1) an experimental plan with objectives that describe why the data are needed and how they will be used, (2) a sampling plan to ensure that representative samples are collected, (3) the use of a certified laboratory or research organization to generate the data from appropriate analyses, and (4) data quality assurance/quality control.

Experimental plans are used to help define the need for the data; summarize the methods that are to be used in analysis of the samples that are collected or generated; identify and note requirements, special procedural issues, or problems (minimum sample sizes, detection limits, preservation techniques, etc.) associated with the analytical methods; and identify how the data will be statistically evaluated.

Sampling plans are used in conjunction with the experimental plans. They describe the type of sampling strategy for sampling a process stream, a pile, a length of pavement, etc. Many types of sampling strategies can be used. Strategies can include simple random sampling, stratified random sampling, staged sampling, composite sampling, and systematic sampling. Some excellent approaches can be found below; they predominantly come from the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO):

- AASHTO T2: Standard Methods of Sampling of Aggregates (also ASTM D75)

- ASTM D3665: Standard Practice for Random Sampling of Construction Materials, Sampling In-Place Paving Materials
- ASTM C702: Standard Practice for Reducing Field Samples of Aggregate to Testing Size
- ASTM D346: The Collection and Preparation of Coke Samples for Laboratory Analysis
- ASTM D1452: Soil Investigation and Sampling by Auger Borings
- ASTM D2234: Collection of a Gross Sample of Coal
- ASTM E122: Choice of Sample Size to Estimate the Average Quality of a Lot or Process
- ASTM D4687: Guide for General Planning of Waste Sampling
- ASTM D5956: Guide for Sampling Strategies for Heterogeneous Wastes
- ASTM D6009: Guide for Sampling Waste Piles
- ASTM D5013: Guide for Sampling Wastes from Pipes or Other Point Discharges
- U.S. EPA (1986) *Test Methods for Evaluating Solid Waste*, SW-846, Office of Solid Waste and Emergency Response, U.S. EPA, Washington, D.C. (This contains an excellent sampling plan and sampling methods section.)
- Clesceri, L.S., Greenberg, A.E., and Eaton, A.D. (1998) *Standard Methods for the Examination of Water and Wastewater*, APHA, Washington, D.C. (This contains an excellent sampling plan and sampling methods section.)
- Barcelona, M.J., Gibb, J.P., Helfrich, J.A., and Garske, E.E. (1985) *Practical Guide for Ground-Water Sampling*, Illinois State Water Survey, Champaign, Illinois

Many other sources are available.

Certified laboratories or other research organizations that rely on standard test protocols and procedures and that are familiar and experienced with the methods can be a reliable source of expertise. They may also be aware of inherent problems of using specific test methods for recycled materials. Such organizations should be able to issue reports that are clear, documented, and contain some evaluation of the quality of the data.

Quality Assurance/Quality Control (QA/QC) methods are frequently used by laboratories to ensure that data meet preestablished quality levels. Methods describing such strategies can be found in the following:

- ASTM D5797: Practice for Generation of Environmental Data Relative to Waste Management Activities: Development of Data Quality Objectives
- ASTM D5283: Practice for Generation of Environmental Data Relative to Waste Management Activities: Quality Assurance and Quality Control Planning and Implementation
- Taylor, J.K. (1987) *Quality Assurance of Chemical Measurements*, Lewis Publishers, Chelsea, Michigan
- U.S. EPA (1980) *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans.* QAMS-005/80, Office of Monitoring Systems and Quality Assurance. ORD, U.S. EPA, Washington, D.C.

- U.S. EPA (1986) *Test Methods for Evaluating Solid Waste*, SW-846, Office of Solid Waste and Emergency Response, U.S. EPA, Washington, D.C. (This contains an excellent QA/QC section.)
- Clesceri, L.S., Greenberg, A.E., and Eaton, A.D. (1998) *Standard Methods for the Examination of Water and Wastewater*, APHA, Washington, D.C. (This contains an excellent QA/QC section.)
- EPRI (1989) *Quality Assurance and Quality Control for Environmental Laboratories*, EPRI GS-6258, EPRI, Palo Alto, California

Normally Distributed Data

Much of the data that are collected in the recycled materials area exhibit a normal distribution, that is, on a value versus relative frequency histogram, the data have a normal or Gaussian distribution that assumes a bell shape. The underlying principle here is that the probability density function is applicable. This is important because many of the statistical procedures used to describe the data (its measure of central tendency, its distribution about the measure of central tendency), establish confidence limits, and test significance require that the data be normally distributed.

In most cases that will be encountered, it is reasonable to assume that the data are normally distributed. While there are methods (described below) to determine whether the data are normally distributed, in many instances the sample size will be too small to provide conclusive answers, and this Gaussian assumption is reasonable.

If sufficient data are available, there are two simple ways to determine if a population of data is normally distributed. The first way involves the use of a simple histogram plotting the frequency of the data versus the actual value of the data. The data are normally distributed if a bell-shaped distribution is seen in the histogram. The second way involves the use of normal probability plots of individual data values on the y axis versus a quantile range. The data x_i are ordered from the smallest to largest value (e.g., $x_1, x_2, x_3, ..., x_n$) for plotting on the y axis. Each ranked statistic is then assigned a quantile according to:

$$(i\text{-}0.5)100/n \qquad (1)$$

where i is the rank number and n is the number of data points in the data set. If the data are normally distributed, the data should lie on an approximate straight line.

Procedures to Transform Non-Normally Distributed Data and Evaluate Outliers

As is the case with some physical and environmental data, it may be known that the data are not normally distributed. This is because the data population can exhibit skewness (which is evident in histograms of probability plots). In such cases, the data must be transformed to make the distribution normal. Numerous transformations can be used; log transformations are most common as these data can have a log normal distribution.

Nonparametric methods can be used to evaluate data in lieu of data transformations. Such nonparametric procedures are valid when the data distribution is unknown or log-normally distributed. Nonparametric tests are called distribution free tests. Frequently, the use of sample order statistics or ranking are used.

Occasionally, data sets may contain outliers. A number of tests are designed to determine if an outlier is present within a population of data describing some measure of central tendency.

The following references contain procedures that address data transformation, nonparametric testing, and allow for examination of outliers:

- McCuen, R.H. (1985) *Statistical Methods for Engineers*, Prentice-Hall, Englewood Cliffs, New Jersey
- Gilbert, R.O. (1987) *Statistical Methods for Environmental Pollution Monitoring*, van Norstrand Reinhold, New York

DO THE SUBMITTED DATA FOR A RECYCLED MATERIAL MEET A SPECIFICATION OR LIMIT?

The applicant and the decision maker will typically need to examine submitted data to see if they meet a specification or are above or below a specified or regulated limit. A couple of approaches can be taken:

1. **Use of two-sided confidence limits about the mean of submitted data for comparison to a specification.**

Here, a two-sided confidence limit for a population mean, μ, is used (Gilbert, 1987, see page 9-5) where the data values, x_i, are assumed to be normally distributed. It is also used when the number of data (n) is relatively small and the variance is unknown. Two-sided limits give an interval in which the true mean is expected. Here, we can use a 95% confidence level, meaning that 95% of the time the sample population mean (μ) resides within the confidence limits. This also corresponds to a significance level (α) of 5%. These confidence limits can then be compared with a specification. In this case, there is no concern if the upper or lower confidence limit is above or below the specification, but rather that the specification falls within the confidence interval. This is referred to as a two-tailed test and the significance is symmetrically split.

The upper and lower confidence limits about a sample population mean, μ, is described by (Gilbert, 1987, see page 9-5):

$$\bar{X} - t_{1-a/2,n-1}\, s/n^{1/2} \leq \mu \leq \bar{X} + t_{1-a/2,n-1}\, s/n^{1/2} \qquad (2)$$

where $\bar{X}$ is the average of n data values (x_i), s is an estimate of the standard deviation (σ), and t is the t statistic. Here, a t statistic for a 95% confidence level or an α of 5% and n-1 degrees of freedom is equally split between the upper and lower confidence limit so that the 5% significance is allocated at 2.5% for both limits.

Example 1:

A blast furnace slag is being used as an aggregate substitute in the hot mix asphalt binder course. The grain size distribution of the material must be similar to a specified distribution. One measure of the grain size distribution, the uniformity coefficient, represents the mass passing the diameter where 60% of the material passes (D_{60}) divided by the diameter where 10% of the material passes (D_{10}) during sieving.

A slag pile has been sampled with a carefully designed random sampling plan and 15 grab samples (n = 15) have been collected and submitted for grain size analysis. The following uniformity coefficients were obtained:

0.60, 0.49, 0.52, 0.59, 0.63, 0.40, 0.53, 0.51, 0.47, 0.50, 0.57, 0.49, 0.51, 0.53, 0.47

Using a histogram, the data appear to be normally distributed. The specification for the uniformity coefficient for coarse aggregates in the asphalt pavement is 0.500. The sample mean $\bar{X}$ is calculated by:

$$\bar{X} = \sum x_i/n \qquad (3)$$

$$\bar{X} = 7.81/15$$

$$\bar{X} = 0.520$$

The standard deviation estimate, s, of the sample mean is calculated by:

$$s = \sum (\bar{X} - x_i)^2/(n-1)^{1/2} \qquad (4)$$

$$s = 0.058$$

The upper and lower confidence limits for a 95% confidence level ($\alpha = 0.05$) requires the use of a t statistic at $\alpha = 0.025$ for n-1 degrees of freedom, which is 2.145 (see Table 9-1 published at the end of this section). The upper and lower confidence limits are calculated by:

$$\bar{X} - t_{1-a/2n-1} (s/(n)^{1/2}) \leq \mu \leq \bar{X} + t_{1-a/2,n-1} (s/(n)^{1/2}) \quad (5)$$

$$0.52 - 2.145 (0.058/(15)^{1/2}) \leq \mu \leq 0.52 + 2.145 (0.058/(15)^{1/2})$$

$$0.487 \leq \mu \leq 0.552$$

Here, the upper and lower confidence limits (at a 95% confidence level) include the specification of 0.500 and the pile is deemed to have the same uniformity coefficient as the standard.

2. Use of one-sided confidence limits about the mean of submitted data for comparison with a specification or regulatory limit.

Here, a one-sided confidence limit for a population mean, μ, is used (Gilbert, 1987, see page 9-5). A one-sided limit is used to make sure that the upper confidence limit does not exceed a specification or regulatory limit or that the lower confidence limit does not fall below a specification or regulatory limit. Again, a 95% confidence level is used.

The upper confidence limit (UCL) for a sample population mean, μ, is described by (Gilbert, 1987, see page 9-5):

$$UCL = \bar{X} + t_{1-a,n-1} (s/n)^{1/2} \quad (6)$$

where $\bar{X}$ is the average of n data values (x_i), s is the estimate of the standard deviation, and t is the t statistic. Here, a t statistic for a 95% confidence level or an α of 5% and n-1 degrees of freedom is assigned completely to the UCL and is not split.

The lower confidence limit (LCL) for a sample population mean, μ, is described by (Gilbert, 1987, see page 9-5):

$$LCL = \bar{X} - t_{1-a,n-1} (s/n)^{1/2} \quad (7)$$

where the variables are as described in Equation (4).

Example 2:

An applicant submits data on the percentage of flat and elongated particles for crushed concrete specimens to be used as coarse aggregate in hot mix asphalt paving. The procedure is based on ASTM D4791, Flat and Elongated Particles. The mix design requires that the coarse aggregate consist of no more than 10% flat and elongated particles.

After carefully sampling the crushed concrete material produced from a processing operation using a stratified sampling plan, the following data were obtained for flat and elongated particles (n = 10):

9.5, 10.3, 11.1, 9.2, 9.0, 9.9, 9.8, 9.7, 10.7, 9.8

Again, using a histogram, the data appear to be normally distributed. The UCL (Equation 6) can be calculated using a t statistic at $\alpha = 0.05$ for n-1 degrees of freedom, which is 1.833 (from Table 9-1), by:

$$UCL = 9.900 + 1.833\,(0.646/10)^{1/2}$$

$$UCL = 10.273$$

Here, the UCL exceeds the specification limit of 10%, and the material is deemed to not meet the limit.

Example 3:

An applicant has submitted data on the Marshall testing of hot mix asphalt pavement made from municipal solid waste bottom ash. One concern from the Marshall test is whether the stability is too low. The Marshall test procedure is based on the Marshall Mix Design Procedure (Asphalt Institute MS-2). For a specific pavement application, it has been specified that stabilities shall not be below 2000 lb.

After careful Marshall mix design testing on representative bottom ash samples (n = 5), the following data were obtained for Marshall stabilities (in pounds):

1950, 2100, 2150, 2200, 2125

Again, using a histogram, the data appear to be normally distributed. The LCL (Equation 7) can be calculated using a t statistic at $\alpha = 0.05$ for n-1 degrees of freedom, which is 2.132 (from Table 9-1), by:

$$LCL = \overline{X} - t_{1-a,n-1}\,(s/n)^{1/2}$$

$$LCL = 2105 - 2.132\,(94.2/5)^{1/2}$$

$$LCL = 2015 \text{ lb}$$

Here, the LCL is above the specified limit and the recycled material is deemed to meet the limit.

ARE THE SUBMITTED DATA SIMILAR TO HISTORIC DATA?

The applicant and the decision maker may also need to examine submitted data to see if they are similar to data in the historical record. There is one approach that can be taken for data sets of either equal or unequal size:

Comparison of Test and Historical Data Sets of Equal or Unequal Size

Here, a two-tailed t test is used to compare the means between two populations of data. However, some procedures are required to examine the variance in the data sets before the comparison can be made.

The sample variance, s^2, is defined by (Natrella, 1963, see page 9-2):

$$s^2 = \sum (\overline{X} - x_1)^2/(n-1) \qquad (8)$$

By definition, the sample variance is the square of the sample standard deviation, s. When two populations of data are used, it is necessary to determine if the variances of both data sets are homogeneous.

Example 4:

Consider the following two data sets for percent fines in a foundry sand; one is historical and one has been submitted for comparison with the historical data set. Here the sample size is the same (n = 15).

Historical Data Set: 1.2, 1.3, 1.7, 1.5, 1.7, 1.9, 1.3, 1.5, 1.4, 1.5, 1.6, 1.5, 1.9, 1.6, 1.4

Submitted Data Set: 1.1, 1.3, 1.7, 2.0, 1.6, 1.4, 1.3, 1.5, 1.4, 1.2, 1.8, 1.8, 1.6, 1.4, 1.6

For the historical data set, $\overline{X} = 1.53$, s = 0.21, and $s^2 = 0.042$. For the submitted data set, $\overline{X} = 1.51$, s = 0.25, and $s^2 = 0.061$.

To test for homogeneity of variance, the following is used:

$$F_{calc} = s^2_{(larger)}/s^2_{(smaller)} \qquad (9)$$

$$F_{calc} = 0.061/0.042 = 1.45$$

This F_{calc} is then compared with an F statistic for a 10% level of significance ($\alpha/2 = 0.05$) or 90% confidence level (from Table 9-2):

$$F_{0.05,\ n-1_{numerator},\ n-1_{denominator}}$$

$$F = 2.48$$

Since $F_{calc} < F$, the variances are assumed to be similar.

After the variances are checked for homogeneity, it is frequently useful to pool the variances. Equation 10 gives a pooled estimate of the variance (Natrella, 1963, see page 9-2):

$$S_p = ((n_{a-1}\, s_a^{\,2} + n_{b-1}\, s_b^{\,2})/(n_{a-1} + n_{b-1}))^{1/2} \qquad (10)$$

where S_p is the pooled standard deviation, S_a and n_a are the standard deviation and the number of data points in population a, and s_b and n_b are the standard deviation and the number of data points in population b.

In the above-mentioned data sets for historical and submitted data, the pooled standard deviation (Equation 10) is:

$$S_p = ((14(0.21)^2 + 14(0.25)^2)/(14 + 14))^{1/2}$$

$$S_p = 0.230$$

Again, a t statistic can be used to compare the means of the two populations (historical and submitted) to see if they differ significantly (Natrella, 1963, see page 9-2):

$$t_{calc} = (\overline{X}_a - \overline{X}_b)/(S_p(1/n_a + 1/n_b)^{1/2}) \qquad (11)$$

$$t_{calc} = (1.53 - 1.51)/(0.23(1/15 + 1/15)^{1/2})$$

$$t_{calc} = 0.238$$

This is compared with a $t_{1-a,n(a-1)+n(b-1)}$ statistic at the 95% confidence level (5% significance level) for n_{a-1} plus n_{n-1} degrees of freedom (using Table 9-1), which is 2.048.

Since $t_{calc} < t$, the two populations are deemed to be similar.

WHAT ARE THE QUALITY CONTROL MEASURES THAT DESCRIBE THE DATA?

The applicant and the decision makers may need to evaluate time-dependent recycled material generation or production data and ask what quality control measures describe the data.

Control charts are useful for determining if current data are consistent with past data (Gilbert, 1987, see page 9-5). Lack of consistency can be the result of outliers or due to shifts or trends in the mean concentrations over time or to changes in variability. Such assessments are crucial for making sure that a process stream deemed previously acceptable by a decision maker is still the same.

A control chart for means is a plot of mean values ($\bar{X}$) of a parameter as a function of sampling event or time. It depicts trends in central tendency by use of a center line for means and upper and lower control limits for the means. A control chart for standard deviations or ranges is a plot of standard deviations (s) or ranges (R) of a parameter as a function of sampling event or time. It depicts trends in variability by use of a center line for range or standard deviation and upper and lower control limits for the range or standard deviation.

The intent of control charts is to select *K* historical data sets and to compute the mean $\bar{X}_1$, range R_i, and standard deviation s_i for each set, where the ith data set contains n_i data values. For control charts for means, if recent or new subgroup means fall within control limits, the time-dependent process is deemed to be "in control" or producing material properties that are still constant with time. For control charts for ranges or standard deviations, if new subgroup ranges or standard deviations fall within control limits, the variability of the material properties is still "in control" and is not changing over time.

The selection process of historical data sets to be used in control charts is important. Rational subgroups must be chosen with care. They can be replicate grab samples from a process stream. They can be replicate samples of a weekly or monthly composite sample. Thought should be given to sources of variability and other factors, such as season, change in processing, or production practices, that can cause changes in properties or variability. When in doubt, if the number of replicates (n_i) in a subgroup is large and the number of subgroups (k) is large, then the greater the sensitivity of the control chart for detecting the changes in time-dependent properties.

Example 5:

Consider the following data set for total chromium content (mg/kg) in foundry sands from casting of stainless steel components:

Data Set (Subgroup) i	Number of Data in Data Set (n_i)	Sample Mean ($\overline{X}_1$)	Sample Range (R_i)	Sample Standard Deviation (s_i)
1	5	490	85	40.3
2	5	520	90	57.2
3	5	600	110	60.8
4	5	590	85	55.3
5	5	570	70	40.7
6	5	480	90	66.4
7	5	620	130	70.1
8	5	580	60	48.7
9	5	450	55	39.5
10	5	620	100	63.6
		$\bar{x} = 552$	$\bar{R} = 87.5$	$\bar{s} = 54.3$

In this case, the number of data (n_i) in each set is equal ($n_i = 5$). Control charts can also be calculated where n are unequal.

The formulas for calculating control charts for means are provided below (Gilbert, 1987, see page 9-5):

	Equal n_i	Unequal n_i
Center Line	$\bar{x} = 1/k\sum_{i=1}^{k}\overline{X}_1$	$\bar{x} = (\sum_{i=1}^{k} n_1\overline{X}_1)/(\sum_{i=1}^{k} n_1)$
Control Limits	$\bar{R}_1 = 1/k \sum_{i=1}^{k} R_i/d_{2i}$	$\bar{s}_1 = 1/k \sum_{i=1}^{k} s_i/C_{4i}$
$n_i \leq 10$	$\bar{x} \pm Z_p\bar{R}_1/n^{1/2}$	$\bar{x} \pm Z_p\bar{R}_1/n_i^{1/2}$
$n_i \geq 2$	$\bar{x} \pm Z_p s_1/n^{1/2}$	$\bar{x} \pm Z_p s_1/n_i^{1/2}$

The formulas for calculating control charts for range and standard deviation are provided below (Gilbert, 1987, see page 9-5):

	Equal n_i	Unequal n_i
Center Line		
Range: Use when $n_1 \le 10$	$\bar{R} = 1/k \sum_{i=1}^{k} \bar{R}_i$	$\bar{R} = d_{2i}\bar{R}_1$
Standard deviation: Use when $n_1 > 10$	$\bar{s} = 1/k \sum_{i=1}^{k} s_i$	$\bar{s}_{2i} = C_{4i}\,\bar{s}_1$
Control Limits		
Range: Use when $n_1 \le 10$	$\bar{R}(1 \pm (Z_p d_3/d_2))$	$\bar{R}_{2i}(1 \pm (Z_p d_{3i}/d_{2i}))$
Standard deviation: Use when $n_1 > 10$	$\bar{s}(1 \pm Z_p(1-C_4^2/C_4^2)^{1/2})$	$\bar{s}_{2i}(1 \pm Z_p(1-C_{4i}^2/C_{4i}^2)^{1/2})$

The variables used in the preceding two tables are as follows:

k	number of historical data sets (subgroups)
n_i	number of data in the *i*th subgroup
Z_p	2 if 2-sigma control limit lines are desired
Z_p	3 if 3-sigma control limit lines are desired
$\bar{\bar{x}}$	grand average of all data over the k subgroups
$\bar{R}$	average range for the k subgroups
$\bar{R}_1$	estimator of the population standard deviation within subgroups when all n_i are not equal; $\bar{R}_1$ reduces to $\bar{R}/d_2$ when all n_i are equal

$\bar{R}_{2i}$	approximate expression for the average range at time i when all n_i are not equal; $\bar{R}_{2i}$ reduces to $\bar{R}$ when all n_i are equal
$\bar{s}$	average standard deviation for the k subgroups
$\bar{s}_1$	estimator of the population standard deviation within subgroups when all n_i are not equal; $\bar{s}_1$ reduces to $\bar{s}/c_4$ when all n_i are equal
$\bar{s}_{2i}$	approximate expression for the average standard deviation at time i when all n_i are not equal; $\bar{s}_{2i}$ reduces to $\bar{s}$ when $n_i > 25$ for each of the k subgroups or when all n_i are equal
d_2, d_3, c_4	correction factors to improve the accuracy of the estimators; these factors (in Table 9-3) are appropriate when the data are normally distributed

Returning to the data in Example 5, since n_i is equal for all 10 subgroups, the center line and upper and lower control limits will be calculated using the equations for equal n_i:

$$\bar{\bar{x}} = 1/k \sum_{i=1}^{k} \bar{X}_i \tag{12}$$

$$= (490 + 520 + 600 + \cdots + 620)/10$$

$$= 552$$

$$R_i = 1/k \sum_{i=1}^{k} R_1/d_{2i} \tag{13}$$

$$= (85/2.326 + 90/2.326 + \cdots 100/2.325)/$$

$$= 37.6$$

$$\bar{x} \pm (Z_p\bar{R}_1)/(n)^{½} \qquad (14)$$

$$552 \pm 2(37.6)/(5)^{½}$$

$$552 \pm 33.6$$

The center line for means (552 mg/kg) is bounded by upper and lower control limits (33.6 mg/kg on either side of the center line). The data can be plotted in a control chart for means as individual X_i for each subgroup on the y-axis and data set (1 to 10) on the x-axis. The center line is added as a horizontal line and the upper and lower control limits are added parallel to the center line on either side.

If the next subgroup mean (or series of means) were to fall outside the upper or lower control limits, then the process would be deemed to be producing a nonconstant material.

A control chart for ranges or standard deviations would be constructed similarly using the previously mentioned equations. If a similar exercise were conducted and subsequent ranges or standard deviations were to fall outside the control limits, then the process would be deemed to be producing a more variable material.

ARE THERE TRENDS IN THE DATA THAT SUGGEST THE DATA ARE CHANGING?

The applicant and the decision maker may need to evaluate time-dependent recycled material generation or production data and ask whether trends in the data suggest that the data are changing with respect to changes in plant operations, processing operations, or other time-based factors.

There are many types of trends in data over time. A number of phenomena can be superimposed on the random distribution about a center line. These include increasing or decreasing trends, cyclical effects (seasonally based or perhaps shift- or process-based), impulses, and step changes. These are depicted in Gilbert (1987, see page 9-5).

The simplest case to analyze, and one that logically follows the use of control charts for means, is the use of a nonparametric test to detect increasing or decreasing trends in historical or as-generated data. The use of statistical tests to identify other superimpositions is detailed in Gilbert (1987, see page 9-5).

Graphical methods such as control charts for means are the first and simplest way to visually assess data and explore if increasing or decreasing trends are apparent. Linear regressions and tests for significance for the slope of the regression can be used. However, a significance test is not appropriate when data are not normally distributed, cycles are present, or the data are serially correlated (Gilbert, 1987, see page 9-5).

The Mann-Kendall test is a nonparametric test for trend. It basically examines the cumulative change in trend over time rather than the magnitude of change. It also is able to handle missing data and detection limit values. It can determine if an increasing or decreasing trend is present. The test requires the use of different procedures, depending on the number of observations. The value of $n = 40$ is used as the cutoff. The observation can be individual measures or means based on multiple observations for a subgroup.

Example 7:

For situations where $n < 40$ data sets or subgroups, consider the following data set of loss on ignition (LOI) values for coal fly ash from a power plant:

Data Set Subgroup i	Number of Data in Data Set (n_i)	Sample Mean (X_i)
1	3	6.5
2	3	6.2
3	3	6.8
4	3	7.0
5	3	7.1
6	3	6.9
7	3	7.5
8	3	7.1
9	3	7.6
10	3	7.8

The data are presented sequentially, as subgroups collected over time (e.g., a mean monthly composite over 10 months).

The Mann-Kendall test looks at the relative magnitude of differences between all values rather than the magnitude of the difference. Hence, the difference may be positive (+), negative (-), or no difference (0).

The data are analyzed using the following series of calculations (Gilbert, 1987, see page 9-5):

	Data Values Listed in the Order Collected Over Time							
x_1	x_2	x_3	x_4	...	x_{n-1}	x_n	No. of + Signs	No. of - Signs
	x_2-x_1	x_3-x_1	x_4-x_1	...	$x_{n-1}-x_1$	x_n-x_1		
		x_3-x_2	x_4-x_2	...	$x_{n-1}-x_2$	x_n-x_2		
			x_4-x_3	...	$x_{n-1}-x_3$	x_n-x_3		
				$\vdots$	$\vdots$	$\vdots$		
				$x_{n-1}-x_{n-2}$	x_n-x_{n-2}	x_n-x_{n-2}		
						x_n-x_{n-1}		
						S =	(sum of + signs)	(sum of - signs)

The Mann-Kendall statistic is then computed using the following:

$$S_{calc} = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(X_j - X_k) \tag{13}$$

which is the number of positive differences minus the number of negative differences. If S_{calc} is a large positive number, measurements taken later in time tend to be larger than those taken earlier in time. The opposite is also true: if S_{calc} is a large negative number, a decreasing trend is present.

Returning to the data set above, the analysis of the data is as follows:

X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	Number of	
6.5	6.2	6.8	7.0	7.1	6.9	7.5	7.1	7.6	7.8	Positive (+) signs	Negative (-) Signs
	6.2-6.5 (-)	6.8-6.5 (+)	7.0-6.5 (+)	7.1-6.5 (+)	6.9-6.5 (+)	7.5-6.5 (+)	7.1-6.5 (+)	7.0-6.5 (+)	7.8-6.5 (+)	8	1
		6.8-6.2 (+)	7.0-6.2 (+)	7.1-6.2 (+)	6.9-6.2 (+)	7.5-6.2 (+)	7.1-6.2 (+)	7.6-6.2 (+)	7.8-6.2 (+)	8	0
			7.0-6.8 (+)	7.1-6.8 (+)	6.9-6.8 (+)	7.5-6.8 (+)	7.1-6.8 (+)	7.6-6.8 (+)	7.8-6.8 (+)	7	0
				7.1-7.0 (+)	6.9-7.0 (-)	7.5-7.0 (+)	7.1-7.0 (+)	7.6-7.0 (+)	7.8-7.0 (+)	5	1
					6.9-7.1 (-)	7.5-7.1 (+)	7.1-7.1 (0)	7.6-7.1 (+)	7.8-7.1 (+)	3	1
						7.5-6.9 (+)	7.1-6.9 (+)	7.6-6.9 (+)	7.8-6.9 (+)	4	0
							7.1-7.5 (-)	7.6-7.5 (+)	7.8-7.5 (+)	2	1
								7.6-7.1 (+)	7.8-7.1 (+)	2	0
									7.8-7.6 (+)	1	-

$S_{calc} = 40 - 4$

$S_{calc} = 36$

We now wish to test at a 95% confidence level (5% level of significance or $\alpha = 0.05$) if the apparent upward trend is valid.

Using Table 9-4, we see that for an S_{calc} of 36 and n = 10, the probability that no trend is present is 0.00018. Since this value is less than the probability level that we are testing at $\alpha = 0.05$, we can deem that an upward trend is present.

For situations where n > 40, the reader should explore procedures outlined in Gilbert (1987, see page 9-5).

Table 9-1. t statistic table (Hays, 1994, see page 9-2).

	Significance Level									
υ	**0.4**	**0.25**	**0.1**	**0.05**	**0.025**	**0.01**	**0.005**	**0.0025**	**0.001**	**0.0005**
1	0.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	0.289	0.816	1.886	2.920	4.303	6.965	9.925	14.089	22.326	31.598
3	0.277	0.765	1.638	2.353	3.182	4.541	5.841	7.453	10.213	12.924
4	0.271	0.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	0.267	0.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	0.265	0.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	0.263	0.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	0.262	0.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	0.261	0.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	0.260	0.700	1.372	1.812	2.228	2.764	3.169	2.581	4.144	4.587
11	0.260	0.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	0.259	0.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	0.259	0.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	0.258	0.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	0.258	0.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	0.258	0.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	0.257	0.689	1.222	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	0.257	0.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	0.257	0.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	0.257	0.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	0.257	0.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	0.256	0.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	0.256	0.685	1.219	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	0.356	0.685	1.218	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	0.256	0.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	0.256	0.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	0.256	0.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	0.256	0.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	0.256	0.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	0.256	0.683	1.310	1.697	3.042	2.457	2.750	3.030	3.385	3.646
40	0.255	0.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	0.254	0.676	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	0.254	0.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	0.253	0.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

Table 9-2. F statistic table (Hays, 1994, see page 9-2).

ν_2 \ ν_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	241.9	243.9	245.9	248.0	249.1	250.1	251.1	252.2	253.3	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.45	19.46	19.47	19.48	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.43	2.38	2.34	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.81
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.85	1.80	1.75	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.84	1.79	1.73	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.82	1.77	1.71	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.81	1.75	1.70	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

Table 9-3. Factors for computing control chart lines (Gilbert, 1987, see page 9-2).

n_i	d_2	d_3	c_4
2	1.128	0.853	0.7979
3	1.693	0.888	0.8862
4	2.059	0.880	0.9213
5	2.326	0.864	0.9400
6	2.534	0.848	0.9515
7	2.704	0.833	0.9594
8	2.847	0.820	0.9650
9	2.970	0.808	0.9693
10	3.078	0.797	0.9727
11	3.173	0.787	0.9754
12	3.258	0.778	0.9776
13	3.336	0.770	0.9794
14	3.407	0.763	0.9810
15	3.472	0.756	0.9823
16	3.532	0.750	0.9835
17	3.588	0.744	0.9845
18	3.640	0.739	0.9854
19	3.689	0.734	0.9862
20	3.735	0.729	0.9869
21	3.778	0.724	0.9876
22	3.819	0.720	0.9882
23	3.858	0.716	0.9887
24	3.895	0.712	0.9892
25	3.931	0.708	0.9896

Table 9-4. Probabilities for the Mann-Kendall nonparametric test for trend (Gilbert, 1987, see page 9-2).

S	Values of n				S	Values of n		
	4	5	8	9		6	7	10
0	0.625[a]	0.592	0.548	0.540	1	0.500	0.500	0.500
2	0.375	0.408	0.452	0.460	3	0.360	0.386	0.431
4	0.167	0.242	0.360	0.381	5	0.235	0.281	0.364
6	0.042	0.117	0.274	0.306	7	0.136	0.191	0.300
8		0.042	0.199	0.238	9	0.068	0.119	0.242
10		0.0083	0.138	0.179	11	0.028	0.068	0.190
12			0.089	0.130	13	0.0083	0.035	0.146
14			0.054	0.090	15	0.0014	0.015	0.108
16			0.031	0.060	17		0.0054	0.078
18			0.016	0.038	19		0.0014	0.054
20			0.0071	0.022	21		0.00020	0.036
22			0.0028	0.012	23			0.023
24			0.00087	0.0063	25			0.014
26			0.00019	0.0029	27			0.0083
28			0.000025	0.0012	29			0.0046
30				0.00043	31			0.0023
32				0.00012	33			0.0011
34				0.000025	35			0.00047
36				0.0000028	37			0.00018
					39			0.000058
					41			0.000015
					43			0.0000028
					45			00000028

[a] Each table entry is the probability that the Mann-Kendall statistic S equals or exceeds the specified value of S when no trend is present.

INTRODUCTION

This chapter presents a list of web sites to assist in the identification of assessment methodologies and criteria for use in recycled material Stage 1, 2, and 3 evaluations. The web sites presented are grouped into the following eight categories: general guidance, air, water, soil, risk assessment, health and safety, modeling, and landscaping material.

GENERAL GUIDANCE WEB SITES

The web sites included in Table 10-1 provide the user with general information on recycled materials, general guidance on how to perform evaluations of the recycled materials, and information on previous experiences using selected recycled materials.

Table 10-1. General guidance web sites.

URL Address	Content
http://www.tfhrc.gov/hnr20/recycle/waste/begin.htm	Main web page for FHWA's User Guidelines for Waste and By-Product Material in Pavement Construction, situated on the Turner-Fairbank Highway Research Center web page
http://www.rmrc.unh.edu	Main web page for the Recycled Materials Resource Center at the University of New Hampshire (a partnership with FHWA's Turner-Fairbank Highway Research Center)
http://www.dot.state.fl.us/emo/pubs/pdeman/pdeman.htm	Florida Department of Transportation: Project Development and Environment Manual
http://www.dot.state.tx.us/insdtdot/orgchart/gsd/recycle/speclist.htm	Texas Department of Transportation: Specifications for re-using recycled materials in construction applications
http://www.dot.state.tx.us/insdtdot/orgchart/gsd/recycle/xperienc.htm	Texas Department of Transportation: Database of Experience With Recycled Materials
http://www.dot.state.mn.us/engserv/environment/research/shredded_tires_paper.html	Minnesota DOT: Comparative Risk Bioassays for Determining the Relative Hazards of Recycled Materials

RISK ASSESSMENT WEB SITES

The web sites included in Table 10-2 provide guidance on risk assessment methodologies and criteria that may be of assistance in determining the potential environmental risks associated with use of a recycled material.

Table 10-2. Risk assessment web sites.

URL Address	Content
http://www.epa.gov/ncea/ecorsk.htm	U.S. EPA: Ecological Risk Assessment Guidance
http://www.epa.gov/iris/index.html	U.S. EPA: Integrated Risk Information System (IRIS)
http://www.epa.gov/reg3hwmd/risk/riskmenu.htm	U.S. EPA Region III Risk-Based Concentration Table
http://www.epa.gov/reg3hwmd/risk/solabsg2.htm	U.S. EPA Region III Technical Guidance Manual Risk Assessment: Assessing Dermal Exposure From Soil
http://www.epa.gov/iris/subst/index.html	List of Substances on IRIS
http://www.tnrcc.state.tx.us/permitting/tox/index.html	Toxicology and Risk Assessment (TARA)
http://www.oehha.ca.gov/risk/chemicalDB/index.asp	California Office of Health Hazard Assessment: Toxicity Criteria Database
http://www.epa.gov/ncea/exposfac.htm	U.S. EPA Exposure Factors Handbook
http://www.dep.state.pa.us/toxicity/	Pennsylvania Department of Environmental Protection: Land Recycling Program Toxicity Database

SOIL WEB SITES

The web sites included in Table 10-3 contain guidance on soil cleanup criteria that could be useful in establishing potential contaminant levels in soils or products.

Table 10-3. Soils web sites.

URL Address	Content
http://www.epa.gov/superfund/resources/soil/index.htm	U.S. EPA: Superfund Soil Screening Guidance
http://www.state.nj.us/dep/srp/regs/soilguide/	New Jersey Department of Environmental Protection: 1998 Revised Guidance Document for the Remediation of Contaminated Soils

AIR WEB SITES

The web sites included in Table 10-4 are U.S. EPA and State web sites listing air quality standards and allowable emissions factors.

Table 10-4. Air web sites.

URL Address	Content
http://www.epa.gov/airs/criteria.html	National Ambient Air Quality Standards (NAAQS)
http://www.tnrcc.state.tx.us/permitting/tox/esl97.html	Effects Screening Levels (ESLs): Used to evaluate the potential for effects to occur as a result of exposure to concentrations of constituents in air
http://www.dec.state.ny.us/website/regs/257.htm	New York State Department of Environmental Conservation: Air Quality Standards
http://www.state.nj.us/dep/aqm/2713915.htm	New Jersey State Department of Environmental Protection: New Jersey Administrative Code, Title 7, Chapter 27, Subchapter 13, Ambient Air Quality Standards
http://www.arb.ca.gov/aqs/aqs.htm	California Air Resources Board: Air Quality Standards and Area Designation Maps
http://www.dep.state.fl.us/ogc/documents/rules/air/62-296.pdf	Florida Department of Environmental Protection: Stationary Air Emissions Standards
http://www.pacode.com/secure/data/025/articleICIII_toc.html	Pennsylvania Department of Environmental Protection: Air Quality Resources and Standards
http://www.dep.state.pa.us/dep/deputate/airwaste/aq/standards/pm/pm.htm	Pennsylvania Department of Environmental Protection: Particulate Matter Air Quality Standards

HEALTH AND SAFETY WEB SITES

The web sites included in Table 10-5 present listings of Occupational Safety and Health Administration (OSHA) air criteria.

Table 10-5. Health and safety web sites.

URL Address	Content
http://www.osha-slc.gov/OshStd_data/1910_1000_TABLE_Z-1.html	OSHA Regulations (Standards - 29 CFR) TABLE Z-1 Limits for Air Contaminants - 1910.1000-1
http://www.osha-slc.gov/OshStd_data/1910_1000_TABLE_Z-2.html	OSHA Regulations (Standards - 29 CFR) TABLE Z-2 - 1910.1000
http://www.osha-slc.gov/OshStd_data/1910_1000_TABLE_Z-3.html	OSHA Regulations (Standards - 29 CFR) TABLE Z-3 Mineral Dusts - 1910.1000

WATER WEB SITES

The web sites listed in Table 10-6 present standards and criteria for drinking water, surface water, and groundwater.

Table 10-6. Water web sites.

URL Address	Content
http://www.epa.gov/OST/Tools/dwstds.html	U.S.EPA Office of Water: Drinking Water Regulations and Health Advisories
http://www.epa.gov/OGWDW/wot/appa.html	U.S. EPA: Current Drinking Water Standards
http://www.tnrcc.state.tx.us/water/quality/standards/index.html	Texas Surface Water Quality Standards
http://www.dec.state.ny.us/website/regs/703.htm	New York Department of Environmental Conservation: Surface Water and Groundwater Quality Standards and Groundwater Effluent Limitations
http://www.state.nj.us/dep/dwq/rules.htm	New Jersey Department of Environmental Protection: Division of Water Quality Rules and Standards
http://www.dep.state.fl.us/ogc/documents/rules/drinkingwater/62-550.pdf	Florida Department of Environmental Protection: Drinking Water Standards
http://www.dep.state.fl.us/ogc/documents/rules/shared/62-520.pdf	Florida Department of Environmental Protection: Groundwater Standards
http://www.dep.state.fl.us/ogc/documents/rules/shared/62-302.pdf	Florida Department of Environmental Protection: Surface Water Quality Standards
http://www.dep.state.pa.us/dep/deputate/watermgt/WSM/WSM_DWM/InfoServ/PAMCLS3.htm	Pennsylvania Department of Environmental Protection: Pennsylvania Maximum Contaminant Levels for Drinking Water

MODELING WEB SITES

The web sites listed in Table 10-7 contain information on software models that can be used to assess the impact of recycled materials use on air and water quality.

Table 10-7. Modeling web sites.

URL Address	Content
http://www.epa.gov/ttn/chief/software.html	U.S. EPA Air Emissions Estimation Software
http://www.epa.gov/scram001/	Support Center for Regulatory Air Models (SCRAM)
http://www.dep.state.pa.us/dep/deputate/airwaste/wm/landrecy/MANUAL/Manual.htm#anchor86714	Pennsylvania Department of Environmental Protection: Fate and Analysis Transport Tools
http://www.camx.com/	Comprehensive Air Quality Model With Extensions
http://www.arb.ca.gov/ccaqs/models/models.htm	California Air Resources Board: Air Quality Models and Guidance Documents
http://www.dot.state.fl.us/emo/software/software.htm	Florida Department of Transportation: Environmental Air Quality Software
http://www.epa.gov/ada/csmos.html	U.S. EPA: General Groundwater Modeling
http://www.ccee.orst.edu/swmm/	U.S. EPA: Storm Water Management Model

LANDSCAPING MATERIAL WEB SITES

The web site presented in Table 10-8 is a link to the U.S. EPA web site guidance document on using biosolids (contains allowable contaminant levels) in land applications.

Table 10-8. Landscaping material web sites.

URL Address	Content
http://www.epa.gov/owm/bio.htm	U.S. EPA: Biosolid Regulations