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STABILIZATION OF MARGINAL SOILS USING RECYCLED MATERIALS

Alaa Ashmawy
Rory McDonald
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Fikret Atalay

Final Report

Florida Department of Transportation
Contract Number BD-544-4
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Disclaimer

Metric Conversion Table

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

Symbol	When you know	Multiply by	To find	Symbol
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")

Symbol	When you know	Multiply by	To find	Symbol
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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16. Abstract

Loose sand, soft clays, and organic deposits are often unsuitable for use in construction due to their less-than-desirable engineering properties. Traditional methods of stabilizing these soils through in-situ ground improvement or replacement techniques are costly. Recycled materials such as scrap tires, plastics, ash, slag, and construction debris provide a viable alternative both for their relatively lower cost and desirable engineering properties. Furthermore, use of recycled materials prevents their disposal into landfills, which are approaching capacity in Florida and across the nation. This report provides a comprehensive assessment of various recycled materials that can be used to stabilize marginal soils in Florida. Particular attention is given to material availability and environmental properties in addition to engineering properties. A methodology is proposed to guide FDOT personnel in evaluating, testing, and approving any new material for use as a highway construction material.

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Executive Summary

The use of recycled materials to stabilize marginal soils offers a viable alternative from economical, technical, and environmental standpoints. Recycled materials provide an attractive alternative to traditional engineering construction materials such as asphalt, concrete, natural aggregate and others. This is due in part to their suitable engineering properties, which allow them to be used as substitute materials in several transportation and geotechnical applications. Equally important, recycled materials offer both economic and environmental incentives. In addition to a lower cost in comparison to traditional materials, their use has the potential to alleviate landfill problems as well as avert costs typically associated with their disposal.

While extensive research has been conducted to investigate the use of recycled materials in engineering applications, the dissemination of the findings is often limited. The problem is compounded by the lack of a single resource containing relevant engineering and environmental characteristics of each material; the tendency of the researchers to publish their findings in technical reports rather than archived publications; and the wide discrepancies among local and state environmental regulations and acceptability. In addition, rapid implementation of recycled materials in highway construction is hindered by the lack of a rational procedure for selecting and approving the use of new recycled materials. Among the problems encountered when a new material is proposed are 1) material availability in terms of quantity and price; 2) environmental impact of the proposed material; 3) consistent mixing and construction methods; 4) quality control in terms of spatial and temporal variability of the properties of the material; and 5) consistent design methods. Although this project does not present new standards, regulations, or specifications, it provides a large body of valuable information and a rational procedure to be followed to assist FDOT personnel in selecting, approving, and implementing the use of recycled materials in roadway construction.

The main objective of this project is to investigate the use of a broad range of recycled materials in geotechnical and transportation applications, and to classify these materials according to relevant factors such as availability, application, environmental impact, and cost. Specifically, it is concerned with the use of such recycled materials to improve the engineering properties of

marginal soils, while maintaining conformance with regulations and practice in terms of the environmental, economical, and practical limitations of such use.

The project involved several components. First, a comprehensive literature review was conducted in order to gather availability information, technical specifications, and parameter data for several recycled materials. Then, through feedback from the FDOT State Materials Office and District Offices, and based on earlier work by other researchers nationwide, a procedure was followed to categorize the types of marginal soils encountered and current solutions, and to classify them according to the appropriate stabilizing mechanism. Next, information was collected on the availability, cost, and earlier performance of all the materials in order to narrow down the list of potential materials which could be implemented for the purposes of stabilizing marginal soils in roadway construction. The following step involved the performance of experiments to investigate the properties of those particular stabilized soils that demonstrated a potential for applicability in Florida or where data in the literature was not adequate. A relational database was developed to compile the data. Mixing methods and other construction-related processes and practical issues were also reviewed as part of the project. Data from large-scale field evaluations and other case histories in the literature were also compiled.

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1. Introduction

1.1. Background

Marginal and weak soils, including soft clays, muck, organic deposits, and loose sand, are often unsuitable for construction due to their poor engineering properties. Site conditions can be enhanced through a number of in-situ ground improvement or replacement techniques, but these alternatives are sometimes costly. Recycled materials, such as plastics, carpet waste, construction debris and wood, are often processed, at the source, into products that can be adapted for a broad range of earth stabilization functions. Examples include recycled plastic lumber, shredded tires, and waste-to-energy ash, which can be used to improve soil conditions in-situ, stabilize weak or failing earth embankments, steepen existing slopes, or modify otherwise marginal soils for use as earth fill.

The use of recycled materials to stabilize marginal soils offers a viable alternative from economical, technical, and environmental standpoints. Recycled materials provide an attractive alternative to traditional engineering construction materials such as asphalt, concrete, natural aggregate and others. This is due in part to their suitable engineering properties, which allow them to be used as substitute materials in several transportation and geotechnical applications. Equally important, recycled materials offer both economic and environmental incentives. In addition to a lower cost in comparison to traditional materials, their use has the potential to alleviate landfill problems as well as avert costs typically associated with their disposal.

1.2. Current State of Knowledge

While extensive research has been conducted to investigate the use of recycled materials in engineering applications, the dissemination of the findings is often limited. The problem is compounded by the lack of a single resource containing relevant engineering and environmental characteristics of each material; the tendency of the researchers to publish their findings in technical reports rather than archived publications; and the wide discrepancies among local and state environmental regulations and acceptability.

In addition, rapid implementation of recycled materials in highway construction is hindered by the lack of a rational procedure for selecting and approving the use of new recycled materials. Among the problems encountered when a new material is proposed are 1) material availability in terms of quantity and price; 2) environmental impact of the proposed material; 3) consistent mixing and construction methods; 4) quality control in terms of spatial and temporal variability of the properties of the material; and 5) consistent design methods. Although this report does not constitute a standard, regulation, or specification, it provides a large body of valuable information and a rational procedure to be followed to assist FDOT personnel in selecting, approving, and implementing the use of recycled materials in roadway construction.

1.3. Project Objectives and Work Plan

The main purpose of this project is to investigate the use of a broad range of recycled materials in geotechnical and transportation applications, and to classify these materials according to relevant factors such as availability, application, environmental impact, and cost. Specifically, it is concerned with the use of such recycled materials to improve the engineering properties of marginal soils, while maintaining conformance with regulations and practice in terms of the environmental, economical, and practical limitations of such use.

The project involves several components. First, a comprehensive literature review was conducted in order to gather availability information, technical specifications, and parameter data for several recycled materials. Then, through feedback from the FDOT State Materials Office and District Offices, and based on earlier work by other researchers nationwide, a procedure was followed to categorize the types of marginal soils encountered and current solutions, and to classify them according to the appropriate stabilizing mechanism. Next, information was collected on the availability, cost, and earlier performance of all the materials in order to narrow down the list of potential materials which could be implemented for the purposes of stabilizing marginal soils in roadway construction. The following step involved the performance of experiments to investigate the properties of those particular stabilized soils that demonstrated a potential for applicability in Florida or where data in the literature was not adequate. A relational database was developed to compile the data using Microsoft Access®. Mixing methods and other construction-related processes and practical issues were also reviewed as part of the project. Data from large-scale field evaluations and other case histories in the literature were also compiled.

1.4. Organization of the Report

This report is organized in eight chapters, a list of references, and appendices. The second chapter includes a review of earlier studies through relevant published literature as well as personal communications. Chapter 3 presents a general physical description of the materials as well as information on the availability and main properties of these materials. Chapter 4 contains a description of processing methods and potential applications for each of the materials based on the information collected. Chapter 5 provides an in-depth description of the engineering (mechanical) and environmental properties of each of the materials, together with recommendations regarding the suitability of the material for improving the properties of marginal soils. Chapter 6 touches on the main economic and cost-related aspects of the materials, and Chapter 7 describes the design and features of the database management system (DBMS). Conclusions and recommendations for implementation of recycled materials in soil improvement programs are found in Chapter 8. The appendices include additional information of direct relevance, which was found in the literature or through the data collection process associated with the project.

2. Literature Review

During the first stages of the project, it was found that a large body of knowledge already exists on recycled material research – spanning some twenty years. The majority of early studies dealt with new material identification and laboratory testing to determine material properties (Collins and Ciesielski, 1994; Edil and Benson, 1998). More recent research has included large-scale field tests, predominantly environmental studies, and processing technique characterization (O'Shaughnessy and Garga, 1999; Liu et al., 2000; Consoli et al., 2002). Perhaps the most surprising finding was the relative lack of documented implementation programs. With so much quality research in recycled materials, it is clear that implementation has not kept pace. This point was tested and reinforced by means of a brief survey sent to the seven Florida Department of Transportation (FDOT) District Offices. When personnel from each District were asked to document the use of recycled materials in their district, very few had had any experience to share. This reinforces the notion that a large gap exists between academic research on recycled materials and engineering practice and implementation.

Despite the presence of research efforts, many tons of potentially useful industrial and domestic by-products are still being discarded each year. Implementation of recycled material programs at the state level has not kept pace with research. This phenomenon can be explained by several factors. Firstly, the lack of a single resource containing relevant engineering and environmental characteristics of each material limits the dissemination of findings. This makes it difficult to adequately compare several materials before deciding to adopt one into practice. Secondly, researchers tend to publish data in technical reports, online sources, and special publications as opposed to archived publications. Sorting through and finding pertinent information can be time-consuming and tedious. Thirdly, the zeal of waste material suppliers to find alternative to landfill disposal, with little attention to quality control and methodical processing, has often resulted in bad experiences with the local and state agencies. As a result, wide discrepancies exist among local and state environmental regulations in terms of material acceptability, which makes it difficult to establish consistent practices among various states and regions. Lastly, the rapid generation of new research exacerbates the existing logistics problem of data organization.

In general, the use of recycled materials can be categorized by stabilizing mechanism, application, marginal soil type, or recycled material type. Two stabilizing mechanisms are identified: discrete and homogenous. In discrete stabilizing, individual elements such as recycled plastic piles (RPPs) are driven into the soil to prevent slope failure and improve global stability. Homogeneous stabilizing, on the other hand, refers to mixing much smaller particles of recycled materials such as plastic strips, shredded tires, ash, or carpet fibers with marginal soils to improve their strength. While classifying the use of recycled materials based on stabilizing mechanism may be attractive when dealing with a specific material or application, such classification becomes impractical when dealing with a substantial variety of materials and applications such as in the present study. Therefore, the most common classifications in the literature have been based on the recycled material itself.

2.1. Comprehensive Resources

A small number of the comprehensive resources available in the literature address the use of recycled materials in highway applications, in general, and their relevant properties, in specific. The main advantage of such resources is that they provide the end user with the basic information needed for initial decision making purposes. However, these resources often lack in detail, and can become rapidly outdated. Based on the information reviewed in the course of the present project, it was deemed reasonable to assume that information that is older than five years, in the field of recycled materials use in highway applications, is either obsolete or needs some updating. The main reason behind this is that manufacturing processes and chemical compositions of recycled material and industrial by-products are governed by the cycle of technology. For instance, the type and properties of plastics that are available for recycling can change significantly over a time span of five to seven years. In addition, new technologies become available over the same time span to provide more efficient and environmentally cleaner means of recycling these materials. Tighter environmental regulations can also render the use of a particular material more difficult in terms of implementation and permitting, which calls for new or modified design methods. Nevertheless, the comprehensive resources available in the literature, albeit outdated, can provide basic material information and useful historic data.

2.1.1. NCHRP Synthesis of Highway Practice - 1994

In conjunction with the National Cooperative Highway Research Program (NCHRP) and the American Association of State Highway and Transportation Officials (AASHTO), a study was undertaken by Collins and Ciesielski (1994) to synthesize the information available on the use of waste materials in highway construction. The report sought to systematically compile useful information before disseminating it to the public. Primarily targeted at "administrators, policy makers, engineers, and others involved in highway construction," the resource contains useful information regarding everything from design considerations and environmental aspects to the economics, availability, and actual highway construction use of waste materials. Organized according to four source identifications – agricultural, domestic, industrial, and mineral wastes – the report addresses the gap between research and practice by admitting that "what has been learned about a problem frequently is not assembled, costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem" (Collins and Ciesielski, 1994).

Although somewhat lacking in detail, their findings are nonetheless more comprehensive than previous work. Information is provided on at least 38 materials. In addition, several processes and applications as well as environmental issues are mentioned for each material. Actual uses in field construction are documented according to the state in which they took place. In general, the source is a very good summary of research and practice in recycled materials before 1994. Excellent data on material availability and detailed state-by-state use of recycled materials in several applications are perhaps the best contributions. Unfortunately, the report lacks detail. Virtually no specific information is available on engineering and environmental properties. Finally, as a printed report, the reader must still search manually for the information of interest. The only way to update the report is to produce a new one.

2.1.2. Recycled Materials Information Database - 1998

Sponsored by the American Association of State Highway and Transportation Officials (AASHTO) and in connection with the Federal Highway Administration, the "Recycled

Materials Information Database" (Chesner et al., 1998) was designed as a single source. Its stated purpose was to provide "a tool that could be used to access from a database, information on recycled material properties, applications, and testing procedures" (Chesner et al., 2003). The database is organized according to twenty waste materials and six applications. After choosing a material, nine primary tabs provide easily navigable access to 28 subcategories. The primary tabs are: General Information, Production and Use, Engineering Properties, Environmental Properties, Applications, Laboratory Testing, Field Testing, References, and contacts. The subcategories range from availability by region and chemical composition by material to construction procedures and bibliographical references. Figure 2-1 shows one screen from the database. The primary tab "Production and Use" and the secondary tab "USA Production" have been chosen for "Coal Fly Ash." Availability or production data is presented in a state-by-state breakdown. Features also allow users to edit and delete both the text and existing tables or create new data tables and figures as new information becomes available.

Perhaps the most important features of the database are its attention to detail, its rigid organization and its facilitation of moving rapidly from one area of interest to another. With a click of the mouse, a user can browse trace metal concentration data for a particular material or view the availability of a different material state-by-state. Another helpful addition is the ability to update the existing resources. A user can add new data as it becomes available. There are however, several drawbacks to this approach. First, the database has a hierarchical relationship structure. Similar to a pyramid, this type of relationship is top down. A user must start the search by first choosing a material, and then progressing to a subcategory involving that material. In order to compare data, it is necessary to go back to the beginning and choose a different material. A hierarchical model has two main deficiencies: 1) the user has to know something either about the subject or about the way in which the data is organized and related and 2) the user cannot easily link information from different branches down the hierarchy or generate queries that span across different subcategories. As a result of these limitations, the database can best be used by an individual with intimate knowledge of recycled material research.

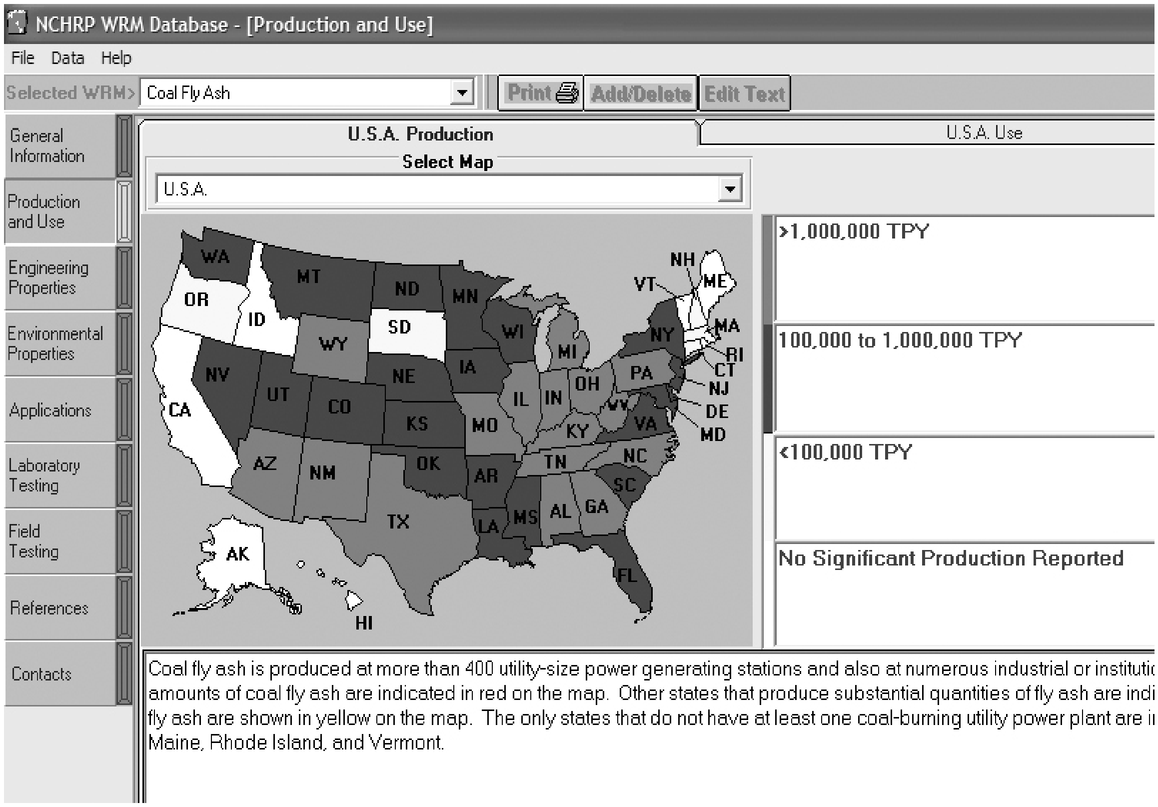

Figure 2-1: "Recycled Materials Information Database" (Chesner et al., 1998)

2.1.3. <u>"User Guidelines" Resource Online - 2003</u>

As a result of recent federal initiatives for recycled material use in highway construction in the U.S., a project was undertaken to provide information on waste materials in specific applications. In addition, the project sought to address issues of suitability for relatively unknown materials and identify areas in need of future research (Chesner et al., 2003). The result, "User Guidelines for Waste and Byproduct Materials in Pavement Construction," is an online resource organized through twenty-one recycled materials and six applications. It is primarily an online version of a technical report, providing users with access to information such as material origin, processing requirements, market sources, management options, and material properties. Many of the tables and other general information in the User Guidelines are borrowed directly from its predecessor, the "Recycled Materials Information Database." Currently, no features exist that allow the user to edit or add to existing information. However, the sheer volume of information available makes it a valuable single, comprehensive resource.

The advantages of the user guidelines are threefold. First, they are very well-organized and detailed. Unlike the printed technical report by Collins and Cielieski (1994), material properties are available in the form of data tables. The second advantage is that the user interface is simple in terms of design and display, thereby allowing the user to move between categories. Finally, by making it available online, users are not required to download the database. However, the system has certain drawbacks. Like the database described previously, the User Guidelines are set up as a hierarchical model. The user may only choose a material or a material/application combination to view the information appertaining to it. This feature requires the user to be familiar with the way the information is organized. The user cannot search and sort by property, availability, or any other subcategory. Similarly, the user has no ability to add, update, or delete information. In Figure 2-2, the User Guidelines page for scrap tires is reproduced.

Figure 2-2: "User Guidelines for Waste and Byproduct Materials in Pavement Construction" (Chesner et al., 2003)

2.2. Specific Resources

A very large number of material-specific and application-specific references are available in the literature, and span a broad range of applications and materials. A largely comprehensive bibliography is provided together with the list of references. The majority of the work is case- or location-specific, and a summary or an annotated bibliography is beyond the scope of a single written report. To address this problem, a relational database, described in Chapter 7, was developed to compile relevant information on the use of recycled materials in highway construction applications. This database provides FDOT with a valuable resource that encompasses previous information published on the subject. The database, in its current form, contains basic information from various key references, but its strength lies in its robust design which allows it to be expanded and updated with more data in the future.

The relational database was selected because of its ability to organize data, simplify the user interface, and ultimately improve implementation of recycled material research. Essentially a collection of interconnected tables, attributes and data, a relational database provides several advantages to traditional methods of organization. For example, such a database stores information in the form of related tables – allowing the same data to be viewed in different ways. The user need not be proficient in database management system structures and does not have to understand the hidden data relations in order to meaningfully interact with it. Through forms, queries, and reports – the fundamental elements of any database management system, the user can rapidly sort through a vast amount of current, relevant data. Furthermore, the database management system is updatable and the design is amendable to account for future expansion. The result is an effective tool to aid in the implementation of recycled material research.

3. Materials and Availability

3.1. Introduction

Although several additional, equally-important parameters exist in the realm of recycled material research, the majority of studies that have been conducted typically begin with specifying the materials that are to be studied. In most cases, researchers select a material about which research has already been conducted in one form or another and test it to determine its predicted performance for a particular real-world application. Usually, there is some type of laboratory program that includes tests for grain-size distribution, plasticity limits, direct shear, triaxial, and many others. Researchers might also conduct mid-size experiments using testing apparatuses and procedures of their own design. For example, Bosscher et al. (1997) performed tests on model embankments in the laboratory so as to generate deformation response data. Other studies have included full-size field testing programs. When used in conjunction with laboratory procedures, these studies have attempted to quantify the performance of recycled materials in various geotechnical and transportation applications.

Most of the more recent recycled material research has focused on one of two aspects: 1) new ways of using existing materials and 2) completely new materials or old materials processed in new ways. A study by Reid et al. (1998) examined the use of rubber tire chips as a method to reduce the bumps at the ends of bridges. This illustrates the specialized nature of some of these new ways to use existing recycled materials. Fahoum (1998) capitalized on local conditions by constructing a road-supporting embankment out of lime taken from the lagoon that the road was to cross. Cleary, these two projects are considered original.

Unfortunately, a portion of the recycled material research available is not quite as original. Certain widely available materials are clearly given preference over more obscure materials. This is not necessarily because the former are more promising, but mostly because of the established track record in terms of quality and consistency of the material properties. As a result, a vast amount of data is available for materials such as recycled tire shreds and fly ash, while a relatively limited amount exists for mill tailings and phosphogypsum. Research is sometimes repeated because of the difficulty in tracking down previous efforts. The tendency of researchers to publish their findings in technical reports, online sources, and in other special publications rather than archived publications exacerbates the problem.

There are various resources that have classified the materials typically used in recycled materials research, including Collins and Ciesielski (1994), Chesner et al. (1998) and Chesner et al. (2003). As described earlier, the first summarizes information on 38 recycled materials, the second contains 20 materials, and the third presents 21 materials. The first study is a comprehensive technical report and the other two are online databases. The full extent of these efforts was outlined in Chapter 2. For the purpose of the current study, it is sufficient to present the materials and provide some rationale for selecting those that will be part of this study. In Table 3-1, the materials included in each of the three earlier studies are marked. Notice the close overlap of materials between the second two studies. This is no surprise as both have the same principal author.

Table 3-1: Comprehensive Material Studies

Recycled Material	**Collins/Ciesielski (1994)**	**Chesner et al. (1998)**	**Chesner et al. (2002)**
Crop Wastes	[shaded]		
Logging/Wood Waste	[shaded]		
Miscellaneous Organics	[shaded]		
Paper/Paperboard	[shaded]		
Yard Waste	[shaded]		
Plastics	[shaded]		
Incinerator Ash (MSW)	[shaded]	[shaded]	[shaded]
Sewage Sludge	[shaded]	[shaded]	[shaded]
Scrap Tires	[shaded]	[shaded]	[shaded]
Compost	[shaded]		
Used Oil	[shaded]		
Coal Fly Ash	[shaded]	[shaded]	[shaded]
Bottom Ash	[shaded]	[shaded]	[shaded]
Boiler Slag	[shaded]	[shaded]	[shaded]
Demolition Debris	[shaded]		
Blast-Furnace Slag	[shaded]	[shaded]	[shaded]
Steel Mill Slag	[shaded]	[shaded]	[shaded]
Non-Ferrous Slags	[shaded]	[shaded]	[shaded]
Cement/Lime Kiln Dust	[shaded]	[shaded]	[shaded]

Recycled Material	Collins/Ciesielski (1994)	Chesner et al. (1998)	Chesner et al. (2002)
Reclaimed Asphalt Pavement			
Reclaimed Concrete Pavement			
Foundry Wastes			
Silica Fume			
Roofing Shingle Waste			
Sulfate Waste			
Lime Waste			
Ceramic Wastes			
Paper Mill Sludge			
Contaminated Soils			
Quarry Waste			
Mill Tailings			
Coal Refuse			
Washery Rejects			
Phosphogypsum			
Baghouse Fines			
Carpet Waste			
Waste Glass			
Flue Gas Scrubber			

3.2. Material Listing

There were several criteria by which materials were included or discarded in the classification system used in the current project. First, and perhaps most importantly, the material must be available in usable quantities in Florida, and must have the potential of being implemented in highway construction. Reliable data must be available about each material selected. With all the parameters used to describe the various materials still to be developed, it was deemed a dubious idea to include an exciting new material about which there is little research available, and which had no potential for implementation. Second, care was taken not to duplicate any material. This could be a problem for certain materials, which can be processed in two or more drastically different ways. Another potential material redundancy problem occurs when one material can be referred to by more than one name. As a brief example, consider incinerator ash, which is also referred to as municipal solid waste combustor ash and waste-to-energy ash. With this in mind, care was taken not only in the selection of materials stage but also during the data collection and synthesis stage. At any rate, the data is updatable and the design is amendable. Any omitted materials may be added immediately and the future discovery of new materials may be added as the research becomes available.

Though by no means a comprehensive list, twenty four (24) materials were selected for further consideration in the present study. These 24 materials provide a robust framework from which to start researching and launch a database. Moreover, they are, by and large, representative of the recycled material research as a whole. Table 3-2 lists these 24 materials.

Table 3-2: Recycled Materials for Current Research

Paper	Demolition Debris	Paper Mill Sludge
Plastics	Blast-Furnace Slag	Wood Waste
Incinerator Ash (MSW)	Steel Mill Slag	Carpet Fibers
Scrap Tires	Non-Ferrous Slag	Mine Tailings
Roof Shingles	Cement/Lime Kiln Dust	Phosphogypsum
Fly Ash (Coal Ash)	Reclaimed Asphalt Pavement	Quarry Waste
Bottom Ash (Coal)	Reclaimed Concrete Pavement	Glass
Scrubber Base (Coal)	Foundry Wastes	Boiler Slag

3.3. General Description of Materials

For the purposes of this project, the 24 recycled materials are divided into three categories based on general origin – domestic waste materials, industrial waste materials, and mineral waste materials. Although some literature features additional categories and subcategories to allow for a more detailed breakdown, the chosen categories are adequate for the current project. Additional subcategories would only serve to complicate user interaction with the database, and are not of use to FDOT applications. It is conceivable that several of the materials could fit into multiple categories (i.e. roof shingles, scrap tires, plastic etc.), but they are included in only one here.

Collins and Ciesielski (1994) suggest dividing the materials into four categories: agricultural, domestic, industrial, and mineral. However, research of “agricultural” materials is extremely limited, and the one material of interest from that category, wood waste, also fits into the industrial byproducts category. Again, it must be emphasized that this list of materials is by no means comprehensive. Other waste materials exist and certainly a range of variations can occur from different processing techniques and can be added later to the database.

3.3.1. Domestic Waste

Domestic waste materials comprise waste generated in the form of post-consumer commercial and household waste. Domestic waste materials include paper waste, plastics, scrap tires, glass/ceramics, and carpet waste.

Waste paper refers to discarded forms of newspaper, magazines, office paper and other paper products of various grades and fibers. According to Tchobanoglous et al. (1993) Waste paper constitutes the largest component of municipal solid waste by weight. The types of paper that are recyclable include newspaper, corrugated cardboard, high-grade paper, and mixed paper. The process of waste paper recycling begins at the community level where it is sorted and left for collection. After collection it is sorted further at the waste collection facility and finally baled or shredded. Although the vast majority of this waste paper is recycled to produce other paper products, its use has been extremely limited in highway applications, mainly in aesthetic applications (Collins and Ciesielski, 1994).

Plastics are much more varied in terms of origin and properties. Trash bags, plastic pipes, milk jugs, battery casings, plastic cups/plates, and plastic soda bottles all are potential sources for waste plastic. These sources are composed of various types of polymers among them polyethylene terephthalate (PETE) in soda bottles, high-density polyethylene (HDPE) in milk bottles, polyvinyl chloride (PVC) in piping, low-density polyethylene (LDPE) in thin film packaging, polypropylene(PP) in crates, and polystyrene (PS) in cups/plates. The properties of the recycled plastic rest mainly on the type of resin or polymer used in the product, as are recycling options and processing. For example, reclaimed HDPE and PETE bottles are granulated into small flakes and separated by floatation. The flakes are then melted and turned into pellets or formed into plastic lumber.

For the purpose of utilizing recycled plastics for marginal soil stabilization, researchers have taken two very different approaches. As a result, they make use of two very different forms of the same material depending on the stabilizing mechanism desired: discrete or homogeneous. Discrete stabilizing incorporates individual elements such as plastic lumber or plastic piles for the purpose of interfering with a failure surface (e.g., Loehr and Bowders, 2000). Homogeneous stabilization on the other hand denotes mixing small pieces or strips of the plastic, usually PET fibers from plastic bottles with soil, pavement, or concrete for the purpose of improving engineering properties such as strength or stiffness (e.g., Consoli et al. 2002).

Scrap tires perhaps rank among the most extensively researched and implemented recycled materials in recent years. Potentially usable forms include whole tires, sliced tires, tire chips, tire shreds, and smaller, soil-like particles referred to collectively as crumb rubber. A typical whole scrap automobile tire weighs about 20 lbs, while a typical truck tire weighs about 40 lbs. However not all of the rubber is recoverable. The size of the tire chips is a function the shredding machine itself. To produce a smaller sized chip, it is often necessary to employ more than one processing machine (Bosscher et al., 1997). Slit tires are basically whole tires spit in half or have had the sidewalls separated from the tread. Shredded or chipped tires undergo two stages of shredding. Primary shredding produces strips 12 to 18 inches in length. Secondary shredding produces lengths of 4 to 6 inches. Ground rubber is produced as regularly shaped and cubical particles as large as ¾ of an inch. Crumb rubber exhibits fine particles ranging in size from passing No. 4 to No. 200 sieves. Composed primarily of various types of rubber, recycled tire shreds also contain carbon black, polymers, and fabrics as well as steel wire or belt materials.

Waste glass typically refers to any recycled, post-consumer glass products. Such products include soda containers as well as windows and similar materials. The majority of recycled glass is used as feedstock for the production of other glass containers, but it is also used in engineering applications. As a product of supercooling, it is composed primarily of silicon dioxide (sand) and sodium carbonate. Crushed waste glass typically exhibits angular particles. Further crushing can cause a decrease in the angularity and produce a material similar in properties to natural sand. Other physical properties of crushed waste glass are variable due to the presence of undesirable materials in the MSW stream such as labels and adhesives. Glass recovery efforts have been centered on recycling facilities. In contrast, ceramic waste is usually produced in the form of materials rejected by factories such as porcelain and china but could also be waste from the home in the form of toilets and sinks. Similar to glass, ceramics waste is crushed to resemble a fine aggregate.

Carpet waste, also referred to as carpet fibers, consists of waste from industrial production and discarded consumer carpet. Essentially, the material is made up of two layers. Yarn-like fabrics are connected by an adhesive SBR, styrene-butadiene latex rubber (Wang, 1999). Nylon face fibers are clumped into the first layer. Before application of the adhesive, a "soft waste" can be produced, which is usually reused in various non-engineering applications (Wang, 1999). However, the post-adhesive carpet waste, or "hard waste" is of interest in this study. Randomly inserted discrete fibers are mixed with soil in small dosages. The properties of these mixtures will follow in this report.

3.3.2. Industrial Waste

Industrial waste materials are byproducts of industrial processes, as opposed to consumer-related domestic waste. Industrial waste materials specified in this study are roof shingles, incinerator ash, fly ash, bottom ash, boiler slag, scrubber base, wood waste, demolition debris, blast-furnace slag, steel mill slag, non-ferrous slag, cement and lime kiln dust, reclaimed asphalt pavement, reclaimed concrete pavement, foundry waste, and paper mill sludge.

Incinerator ash, also referred to as waste-to-energy (WTE) ash, is produced from the burning of municipal solid waste (MSW) at mass incineration facilities to reduce its volume. There are two types of combustors used in burning MSW: mass burn and refuse derived fuel (RDF). In a mass burn combustor, minimal processing is given to the MSW before incineration. This implies that incombustible and/or hazardous wastes that may be incorporated in the MSW stream, are fed into the combustor. Facilities utilizing RDF combustors handle MSW that has been sorted and processed. The processing of MSW prior to combustion includes shredding and sorting in order to remove incombustible and potentially hazardous metals. The majority of incinerator facilities in Florida are mass burn facilities.

The residue from the incineration process consists of combined ash, which is made up of two components – bottom ash in larger proportion and fly ash in smaller proportion. Bottom ash is lighter in color and because it is usually moist, it produces little dust. Overall, it resembles a porous, gray, sitly sand containing gravel. It may also contain very small amounts of organic material that has not combusted as well as pieces of metal. Fly ash is collected from the air pollution control system and consists of darker, finer, particles similar to a powder. Usually, both bottom and fly ash from incinerator facilities are combined for disposal. Incinerator ash has been approved for limited use in highway construction by FDEP, but reservations still persist due to its tendency to leach marginally hazardous concentrations of heavy metals. For each proposed use, a beneficial use demonstration (BUD) is required before FDEP approval is secured. Moreover, county and local environmental regulation agencies may have stricter rules on the use of such material than FDEP.

Fly ash is a byproduct that results from the combustion of coal at energy producing facilities. During the combustion process, the ash is carried off and collected from the flue gas produced. The amount of fly ash produced is dependent upon the type of boiler and also the form of coal. Pulverized coal combusted in a dry bottom boiler will yield 80 percent of total ash produced as fly ash. Pulverized coal in a wet bottom burner will yield 50 percent fly ash. Crushed coal in a cyclone furnace will yield 30 percent fly ash (Chesner et. al. 2002). Predominantly a fine-grained, powdery material, fly ash boasts a variety of appearances, chemical compositions, and material properties. These variations are due to discrepancies in parent coal properties, burning mechanisms, and material handling (Vipulanandan et al., 1998). Even so, constant constituents include silica, alumina, iron oxide, lime, and carbon (Vipulanandan et al. 1998). Four types of coal are burned to produce fly ash: anthracite, bituminous, lignite, and sub-bituminous. Individually, they produce two types of fly ash, which are characterized by calcium oxide content. Class-F fly ash contains less than 10 percent CaO, and it comes from anthracitic or bituminous coal. Class-C fly ash contains more than 10 percent CaO, and it comes from lignite or sub-bituminous coal (Vipulanandan et al. 1998). For facility of data interaction, this study lumps both types of fly ash into a single material.

Bottom ash, another coal burning byproduct, consists of a dark gray, coarse, well-graded material that is produced in combination with coal combustion processes. The ash is collected in water filled hopper at the bottom of the furnace. Once an adequate amount has been produced and collected into the hopper, water at high pressures is applied to remove the material. Once removed, it is transported to disposal ponds or basins, dewatered and crushed, then stockpiled for disposal. Bottom ash exhibits a dark gray color, with angular particles and a porous texture. The size of the particles can vary from fine gravel to fine sand. The ash is typically well-graded, however there may be differences in the particle size distribution among ashes from different facilities. In addition, particle agglomerates can break down into smaller size particles during handling.

Boiler slag and bottom ash are very similar materials. First, they both are byproducts of the coal burning process. Second, they exhibit very similar physical and mechanical properties. In fact, the two are often combined by researchers and considered as a single material. However, the production of either bottom ash or boiler slag depends on the type of coal-burning furnace. Boiler slag is produced by collecting the coal ash in a hopper containing quenching water. When the molten ash comes into contact with the water it crystallizes and forms black glassy angular pellets when crushed. The material is poorly-graded and smooth in texture, and it is generated in much lower quantities than both fly ash and bottom ash. Because of the difference in physical appearance, gradation, and particle size from bottom ash, boiler slag is listed separately for the purposes of this research project.

Scrubber base is the term given to a composite recycled material that is a by-product of coal combustion. Also referred to as general sulfate waste or as FGD scrubber material, it is an equal parts mixture of flue gas desulfurization sludge (FGD) and fly ash (Vipulanandan and Basheer, 1998). The former compound originates from a method to reduce SO_2 emissions during the burning of coal in electric power plants. The process consists of introducing alkali (primarily limestone), in spray form, into the exhaust system of the boiler. The alkali reacts with the sulfur dioxide gas and is then collected as a calcium sulfate slurry or a calcium sulfite liquid. As the solid material settles out before reuse, the leftover sludge is termed the scrubber base. This scrubber system, as it is termed, yields a whitish calcium sulfite or calcium sulfate slurry.

Calcium sulfite slurries are thixotropic (i.e., they harden with time) and are generally more difficult to handle and treat than calcium sulfate slurries (Collins and Ciesielski, 1994).

The scrubber base sludge may then be treated by fixation and stabilization. Stabilization involves adding dry materials to the dewatered sludge, such as fly ash, in order to ease the handling of the material and to prevent seepage. Fixation involves the addition of chemical reagents such as Portland cement or lime to convert the already stabilized material into a solidified mass. Dewatered scrubber base is generally collected as calcium sulfite, although some coal combustion facilities produce the waste as calcium sulfate (gypsum). The particle sizes of dewatered and unstabilized material range from sand to silty-clay.

Blast furnace slag is a waste by-product of the iron production process. Iron ore is charged into a blast furnace along with limestone that will serve as a flux in the process. The fuel used in the blast furnace is a mixture of coal that has been crushed into a powder and cooked prior to use. The combustion of the fuel, termed coke, produces carbon monoxide, which in turn transforms the iron ore to liquid iron. Blast furnace slag is produced in a molten liquid form during the combustion process (Chesner et. al. 2002). Different types of blast furnace slag can form depending upon the method used to cool the slag after it leaves the furnace. The different types that may be produced include air cooled blast furnace slag, expanded or foamed slag, pelletized, and granulated blast furnace slag. Air cooled slag is produced as the liquid slag is allowed to slowly cool at around room temperature. The end result is a crystalline, hard, substance formed in lumps that may be crushed and screened. When the cooling process is accelerated by the addition of water or air to the molten slag, expanded or foamed slag is produced. Pelletized slag is produced when the molten slag is cooled in a spinning drum with the addition of air and water. The slag may be granulated by a rapid quenching process where minimal crystallization is allowed to occur.

The chemical composition of blast furnace slag is primarily alumina-silicates, and calcium-alumina-silicates. Each type of slag will exhibit different properties. Air cooled slag when crushed, consist of angular particles with textures ranging from rough and porous to smooth and glassy. Crushed expanded slag particles are also angular but the texture is rougher in comparison to air cooled. Pelletized blast furnace slag exhibits smooth texture and rounded particles. Granulated slag is a glassy granular material that can vary from large and coarse to dense sand.

Foundry sand is a major by-product of the metal casting industry. Sand is used as molds and cores in metal casting because of its thermal conductivity properties. Typically, most sand cast molds use green sand, which consists of high quality silica, with small quantities of bentonite, water, and carbonaceous additive (Abichou et al., 1998). The bentonite is added to the sand to act as a binder, and the carbonaceous additive to enhance the finish of the cast. Chemically bonded sands with organic binders are also used in the sand casting industry, although its use is small in comparison to green sand. Waste foundry sand (WFS) exhibits highly uniform properties in grain size distribution, but can also include some foundry dust (Edil and Benson, 1998). The particles are evidently in the sand size range and can be sub-angular to rounded in shape. After its use in metal casting, WFS may contain contaminants such as heavy metals, which are introduced to the sand during the casting process while the sand mold is in contact with molten metal.

Steel mill slag is a by-product of steel production when separating molten steel from the furnace. During the process of steel making, liquid blast furnace metal, scrap, and fluxes are charged into a furnace. Oxygen is then injected into the furnace at high pressures. The oxygen reacts with impurities to separate them from the product. At the end of the process, the liquid steel is poured out and the steel slag is retained and eventually tapped out.

Different grades of steel will yield varying properties in the slag that is produced because of the variation in carbon content. Different types of slag are also produced at different stages in the steel making process. These can be referred to as furnace, raker, ladle, and pit slags. Furnace slag is the material initially tapped out of the furnace. When the steel is transferred by ladle for additional refining, more flux is added to further melt the steel. The material left over is called raker and ladle slag. The material that falls onto the floor during the process or that is removed from the ladle is referred to pit slag. Furnace slag is the main source for a reusable aggregate material since the addition of fluxes is minimal. Steel slag aggregate exhibits high angularity and rough surface texture.

Non-ferrous slag, as the name implies, is generated from the recovery and processing of natural ores other than iron. Primarily, this includes copper, phosphate, lead, nickel, and zinc (Chesner et al., 2002). Copper and phosphate slags are the most prevalent. Like steel slags, the initial molten byproduct evolves into a hard, aggregate material as it is cooled. Obviously, non-ferrous slags are really the name given to several different materials that exhibit similar albeit unequal properties. Because non-ferrous slag data is limited, the materials will all be included under the generic non-ferrous slag material heading.

Non-ferrous slag can be dark black to brown or red and either glassy or dull depending on the metal from which it was processed and the method used. Nickel slag can be reddish brown, brown, or black in color. The particles when granulated, are angular but smooth, and exhibit a glassy texture. Copper slag is black and glassy in appearance with smaller particles than nickel slag when granulated. Phosphorous slag appears black to dark gray in color. The particles are uniform and angular when granulated. Lead and zinc slag are similar in appearance. Their color can range from black to red and have a glassy look.

Kiln dust is the by-product of rotary kiln operations such as in the production of Portland cement. During such operations dust is collected via an air pollution control system. Portland cement production yields two types of kiln dust, cement and lime. Both cement and lime kiln dusts are fine, dry, powdery substances, but they exhibit very different chemical properties. While cement kiln dust can contain reactive calcium oxide, lime kiln dust is potentially more reactive due to its free lime composition (Collins and Ciesielski, 1994). Both dusts may contain hazardous substances.

Construction and demolition waste, or C&D as it is referred to, is the general term for a host of waste materials generated from the construction industry. Consisting of building materials such as concrete, glass, brick, metal, wood, and plaster, C&D waste must be processed, mainly by separation, before it can be incorporated into engineering uses. Because C&D waste is a highly heterogeneous material, a comprehensive characterization is difficult to achieve. The processing of demolition debris involves a series of separations and screenings, starting with the larger materials (lumber, concrete) down to the sand and gravel sized material. Upon arrival to the processing facility the incoming material is separated into concrete and non-concrete materials. The non-concrete material passes through several screens and conveyors in order to remove harmful materials such as asbestos. The concrete material is crushed and a magnet is used to remove any metal and rebar present (McMahon, 1997).

Some researchers have considered construction and demolition debris as a parent category for roof shingles, reclaimed asphalt pavement, and reclaimed concrete pavement. However, the latter three materials are separated in this study because of their distinct properties and large quantities. Some of the remaining C&D waste raises the question of possible contamination from asbestos and other hazardous materials. In addition, variability and quality control of properties remains one of the main issues; once the waste is separated and sorted, the quality of each of the sub-components needs to be verified. The quality of the leachate from C&D waste containing gypsum and other building materials has also been questioned by FDEP. While certain components of C&D waste may be useful for improving marginal soils, the lack of consistency in what remains of the material after separating the useful components (concrete, wood, etc.) makes is less attractive than other alternatives.

Reclaimed asphalt pavement, also known as RAP, is generated as roads are repaired or replaced. RAP consists of asphalt and aggregate and must be processed to become a usable recycled material. Once the asphalt is removed, it is typically transported to a processing facility where screening and crushing of the material takes place. Before processing, the material resembles non-uniform over-sized aggregate that is black to gray-black in color. Since RAP is either milled or crushed during removal, there are noticeable differences in the gradation of the aggregates; Milled RAP typically exhibits fine particles while crushed RAP contains larger particles. Other factors also affect the particle size distribution of RAP, including the equipment used in removal and production and the type of aggregate in the pavement.

Reclaimed concrete aggregate (RCA) and reclaimed concrete pavement (RCP), also referred to as recycled concrete, is another by-product of roadway demolition, but it varies in composition more than RAP (Papp et al., 1998). Cement structures such as roads, bridges, sidewalks, buildings, foundations, and retaining walls can generate reclaimed concrete pavement material.

Because the method of installation, exposure to environments, and concrete type and quality can all vary dramatically among these structures, uniformity in type and quality of reclaimed concrete pavement is difficult to achieve (Collins and Ciesielski, 1994). The processed material is typically a well-graded gray aggregate. The particles are rough in texture and high in water absorption compared to natural aggregates of the same size.

Roof shingles waste consists of both discarded industrial waste shingles and surplus domestic shingles used on houses. Two distinct types of byproducts are normally considered. The first type is “prompt roofing shingle scrap” or “roofing shingle tabs” (Chesner, 1998). This type is a by-product of the manufacturing process as is generated at the factory as new shingles are formed to their specified dimensions. The second type, “tear-off roof shingles,” is a by-product of building repair or demolition and is thus generated as existing roofs are replaced or removed.

Discarded roofing shingles are shredded and processed into different sizes, varying from well-graded lumps to poorly-graded fines (Chesner et. al. 2002). Consisting of asphalt, fiberglass, aggregate and other additives in various concentrations, roof shingles waste is non-uniform. Similar to tire shreds, the type and size of roof shingles waste varies dramatically depending on the processing mechanism. The waste can range from a well-graded, irregularly-shaped, coal-like byproduct to poorly-graded, black, sand-sized fines. The composition of discarded roofing shingle tabs is essentially equivalent to the virgin shingles; however the quality and composition of tear-off roofing shingle scrap can be quite variable. Discarded tear-off roofing shingles may also contain other materials such as nails, metal flashings, wood, and other materials accumulated over its lifecycle.

Paper mill sludge is a by-product of the pulp and paper industry. Edil and Benson (1998) cite residues from wastewater treatment plants at paper mills as the primary source for this material. The material is also mixed with sand to produce a more uniform aggregate-type material. The sludge has a physical appearance similar to muck. In addition to organic material and water, the sludge is also comprised of mineral fines, typically kaolinite or calcite. Compared to clay, paper mill sludge can be characterized as having a high water content, low specific gravity, and high organic content (Moo-Young and Zimmie, 1997). Another by-product of the industry is spent sulfite liquor, which can be used as a roadway binder.

Wood waste can be categorized according to its source of generation. Harvested wood waste is generated by land clearing and forest management activities. Mill residue is waste generated primarily by pulp, paper, and lumber mills, and secondarily by manufacturers of furniture, cabinets, etc. Other sources include pallet and container waste, construction and demolition waste, and yard wastes (Tchobanoglous, 1993).

Recycling options are dependent upon the source of generation. For example, when waste wood from C&D waste is initially brought into the recycling facility, it is inspected for contaminated members (pressure treated, painted) and other undesirable material (dirt, rocks). Upon separating the unwanted material, the wood waste is typically shredded into chips. The chips can then be grinded further to produce a finer material if so desired. The few researchers who have examined this waste material have categorically limited it to mulching applications and some lightweight fill applications. The material can also be used in temporary stabilization of access roads.

3.3.3. Mineral Waste

Finally, mineral wastes result from mining activities or more specifically, the extraction of ores and minerals. Mineral waste materials: quarry waste, mill tailings, and phosphogypsum. Again, it must be emphasized that this list of materials is by no means comprehensive. Other waste materials exist and certainly a range of variations can occur from different processing techniques. However, the list is adequate for the intended use.

Quarry waste is a general term for any material that is generated from the processing of stone at quarries. A series of processes produces different types of quarry waste: screenings, setting pond fines, and baghouse fines. Screenings are the fine fractions of crushed stone produced after the stone is initially crushed and separated with a No. 4 sieve. Settling pond fines are produced as the stone is washed after crushing in order to separate coarser aggregate. The fines in the wash are discharged to settling ponds where settlement occurs by gravity. Baghouse fines can be describes as the dust collected at dry plants. At dry plants, dust collection systems such as a baghouses or cyclones are used to collect dust generated from the crushing of stone (Chesner et. al. 2002). For the purpose of the current research project, they will be treated as one material. Both the consistency and composition of this waste varies with the geographic location of the quarry, but the product is usually characterized by small pieces of chipped rock and fines.

Mine tailings, also known as mill tailings, are a byproduct of the ore concentration and extraction processes. They consist of the fine particles rejected from the processing of raw ore and are produced initially in slurry form before being allowed to settle and consolidate in containment ponds. Mill tailings range in size from sand to silty-clay, but the particles are generally characterized as hard, angular, aggregate-type material composed of significantly large fractions of fines. Like many of the other materials, mill tailings vary greatly in terms of particle size, physical and chemical properties. This is due to a variety of factors such as processing, disposal, and type of ore.

Phosphogypsum, sometimes included in the more general category, sulfate waste, is another mineral waste material. It is generated from the production of phosphoric acid from phosphate rock. Composed of calcium sulfate hydrate, the final by-product is a wet, gray, silt-sized substance. There are concerns as to its impact on the environment as expressed by the EPA and FDEP over radon contamination. However, the sheer volume of phosphogypsum produced in Florida makes it an interesting material to investigate and include separately from other mine wastes.

3.4. Material Availability

Availability data is widely scattered and difficult to concretize. This is due mainly to two factors. First, availability of materials changes each year, and there is currently no resource available that tracks these changes. Second, researchers tend to publish their findings on individual materials in technical reports and online sources rather than archived publications. This makes the process of comparing availability data supplied by researchers tedious and time-consuming. Appendix I contains a summary of material providers around the State. The list is by no means comprehensive, but it provides a good starting point for industry contacts if needed.

The comprehensive relational database approach is envisioned as a way to not only organize availability data from a variety of sources, but also track annual changes in the data. A brief attempt is made here in Table 3-3 to present published availability data at the national level to provide a robust framework for the purpose of comparison.

Table 3-3: Material availability at the national level (Million tons per year)

Recycled Material Name	**Collines/Ciesielski (1994)**	**Chesner et al. (1998)**	**Chesner et al. (2002)**
Paper	71.8		
Plastics	14.4		
Incinerator Ash (MSW)	8.6	9	9
Scrap Tires	2.5	2.6	2.6
Roof Shingles	10		11
Fly Ash (Coal Ash)	48	54.8	59.4
Bottom Ash (Coal)	14	16.1	16.1
Scrubber Base (Coal)	18	23.8	23.8
Demolition Debris	25		
Blast-Furnace Slag	16		15.5
Steel Mill Slag	8	8.3	8.3
Non-Ferrous Slag	10	9	9
Cement/Lime Kiln Dust	24	18.2	18.2
Reclaimed Asphalt Pavement	50	45	45
Reclaimed Concrete Pavement	3		
Foundry Wastes	10	15	15
Paper Mill Sludge			
Wood Waste	70		
Carpet Fibers	2		
Mine Tailings	520	500	500
Phosphogypsum	35	35	35
Quarry Waste	175	175	175
Glass	12.5	10.1	10.2
Boiler Slag	4	2.6	2.6

3.4.1. General Observations

There are several interpretations that can be made from Table 3-3. The oldest source contains availability data for the greatest number of materials. This fact makes it impossible to do a comprehensive comparison of availability data for all materials over time. Even so, the availability data for materials considered in each of the three sources shows a slight increase, generally speaking. There are however, a few noticeable exceptions. The availabilities of non-ferrous slags, kiln dusts, reclaimed asphalt pavement, and glass all seem to have decreased slightly in recent years. Perhaps these decreases are a result of increased industrial efficiency and conscious internal reuse of byproducts or perhaps they are a result of less-than-efficient data collection.

3.4.2. Availability in Florida

In the state of Florida, **waste paper** constitutes approximately one fourth (25%) of the Municipal Solid Waste (MSW) stream, which equates to roughly 6.4 million tons per year (FDEP, 2003). Out of these 6.4 million tons, approximately 1.9 million tons were recycled, leaving approximately 4.5 million tons unused or landfilled. This is a significant quantity; however, the poor engineering characteristics, such as low tensile strength, sensitivity to moisture, and biodegradability of paper make it unsuitable for geotechnical engineering applications. As such, it was envisioned that paper is not a suitable candidate for use in soil stabilization applications, and further testing on the material was not performed.

Waste plastics constitute approximately 5 percent of Florida's MSW stream, which equals to approximately 1.3 million tons per year. Approximately 55,000 tons out of these 1.3 millions tons are recycled each year, which leaves 1.25 million tons land-filled each year. One of the beneficial reuse applications of plastics includes the production of plastic piles or plastic lumber, which can be used in place of concrete or timber piles in soil stabilization applications such as erosion control and slope stability. Other beneficial uses include mixing the plastic strips with loose sand to add to its shearing resistance, although earlier research has suggested that this option is not cost-effective (Coulet et al., 1990; Benson and Khire, 1994).

In Florida, approximately 200,000 tons of **scrap tires** are collected each year. Current beneficial uses of tires include tire derived fuel (TDF), which eliminates some 70,000 tons of the total supply of waste tires, and other recycling applications which accounts for 60,000 tons. In addition, close to 20,000 tons are currently used in beneficial roadway applications in the form of crumb rubber for asphalt. This leaves 50,000 tons which could be used for beneficial roadway applications. Potential applications include lightweight fill, filters, and drains.

Glass makes up approximately 3 percent of Florida's entire MSW stream, equaling approximately 740,000 tons per year. Out of this amount, approximately 170,000 get recycled, leaving 570,000 tons per year for possible beneficial re-use applications. While possible applications include the use of glass in place of crushed aggregate, questions still remain regarding the presence of trace toxic materials in glass bottles and containers.

Carpet waste accounts for approximately 300,000 tons of the annual waste in Florida. While most of the carpet waste is still being landfilled, and the quantities generated seem adequate for consideration in roadway construction purposes, past experience with this material (e.g., Wang, 1999), as well as additional testing conducted in conjunction with the current project, indicate a degradation in the properties of base and subgrade materials when mixed with carpet fibers. An alternative use of recycled carpet fibers may be in the field of rigid pavement, to act as a reinforcement fiber in concrete to reduce shrinkage and increase toughness (Wang 1999).

In Florida, there are 14 waste incineration or waste-to-energy (WTE) facilities with a combined largest capacity of any state in the nation. Florida's WTE facilities have the capacity to generate over 500 megawatts of electricity daily. Approximately 1.5 million tons of **incinerator ash** is produced annually as a result of the incineration activities. Currently, almost 100 percent of the 1.5 million tons is stockpiled or land-filled either on-site or at remote locations. Therefore, incinerator ash is a very good candidate for a beneficial reuse application in soil stabilization; provided that this material proves to not have any harmful effects on the environment and that it actually improves the characteristics of the soil. Results of environmental properties and geotechnical tests for incinerator ash can be found in Chapter 5 of this report.

Approximately 2 million tons of **<u>fly ash</u>** is produced each year by the major coal-burning power plant facilities in the state of Florida. With advances in recycling technologies over the past few years, more than 99% of the fly ash produced by power plants in Florida is reused in applications such as cement and concrete production, and rigid pavement construction. As a result, fly ash availability for the purpose of improving soil properties is insignificant. The current implementation of fly ash in concrete production is approved by FDEP, and the process is well established.

<u>Bottom ash</u> from coal combustion is produced in very small quantities in Florida (less than 50,000 tons per year), and all of it is beneficially reused in concrete and roadway base applications. As such, no addition material is available for the purposes of improving the properties of marginal soils in Florida.

Approximately 75,000 tons of **<u>boiler slag</u>** is produced by coal-burning facilities equipped with boilers in the state of Florida. Out of these, approximately 98% gets beneficially re-used in applications such as roofing granules and blasting grit, structural fill and mineral filler. Once again, since this material currently has many beneficial re-use applications in place, availability for other applications such as soil stabilization is scarce in the state of Florida.

<u>Scrubber base</u> is produced in Florida at coal combustion facilities and incinerators in large quantities - approximately 800,000 tons annually. However, the vast majority of scrubber base (close to 95%) is beneficially re-used in applications including gypsum and wallboard production, and cement and concrete production. As such, the material is not a strong candidate for further investigation regarding its engineering properties for roadway applications.

There are no significant quantities of **<u>blast-furnace slag</u>** produced in the state of Florida. An exact quantity of blast-furnace slag produced could not be obtained since there aren't many companies that operate blast furnaces in Florida and those that do operate them do not keep track of amount of slag produced. Based on personal communications with the producing facilities, the amount produced does not warrant the need for additional testing to be performed on the material due to availability issues.

While the majority of **waste foundry sand** is sent to landfills, the production of such materials is very limited in Florida. There are no documented statistics of waste foundry sand in Florida, but the quantity produced nationally is around 10 million tons, the vast majority of which is produced in the Great Lakes and Midwest states, where foundries for the heavy industries such as automotive engines are located. Based on personal communications, it is assessed that less than 50,000 tons of the material is produced annually in Florida, which does not warrant the need for further consideration due to the limited availability.

Approximately 100,000 tons of **steel mill slag** is produced in the state of Florida annually, mainly by Gerdau-Ameristeel Corporation who is the only major steel mill operator in the state of Florida. Currently, 100 percent of the steel mill slag produced by Gerdau-Ameristeel is already being beneficially reused as granular base or as an aggregate material in construction applications.

Nonferrous slag is available in smaller quantity than steel mill slag in Florida. The exact numbers for each type of ore were not of interest because 1) the majority of nonferrous slag is being recycled or beneficially reused, 2) the remaining quantity is too small to warrant any additional evaluation for beneficial use, 3) the chemical composition and environmental safety of each type of slag are different depends on the parent ore, so a general guideline could not possibly be developed for such material.

Cement producers in the state of Florida have almost entirely switched over to self-contained dry kiln systems, where the cement/lime kiln dust produced during the process gets reintroduced into the system which prevents the production of any waste material. Therefore, currently there is little or no **cement/lime kiln dust** available for beneficial re-use in Florida. The little amount of cement/lime kiln dust that is left over from the old kiln systems is still available in stockpiles, however, issues such as limited availability, the high pH content of this waste material and the high transport costs associated with hauling the material from its original source onto the actual job sites make this material undesirable for beneficial re-use purposes.

Construction and demolition waste (C&D) makes up a significant portion of the municipal solid waste produced in Florida – around 30%. The total amount of C&D debris generated in the state of Florida annually is estimated to be 10 million tons. Out of the 10 million tons of C&D debris generated, approximately 3.3 million tons, or 33 percent, is recovered for reuse or recycling. The remaining 6.7 million tons, which are landfilled, exhibit highly variable properties in terms of composition and hazardous substance content. An evaluation of such material for use in soil stabilization can not be conducted due to the lack in quality control of the material.

Although exact quantities of **reclaimed asphalt pavement** (RAP) and recycled concrete pavement and aggregates (RCA) are not available, almost 100% of these materials is currently being used in roadway applications and other beneficial uses. As such, no additional quantities are available for new uses in marginal soil stabilization. Detailed information on each of these materials of relevance to FDOT is provided in Cosentino and Kalajian (2001), Cosentino et al. (2003), and Kuo et al. (2001).

In Florida, the **roof shingles** market amounts to more than $1 billion annually, with approximately 1 million tons of recyclable roof shingles material generated each year. Currently, the Florida Department of Environmental Protection (FDEP) has reservations on the beneficial re-use of tear-off roof shingles due to concerns about variability and quality control *vis-à-vis* the potential presence of asbestos in the shingles that are collected. However, it has also been shown that roofing shingle tabs – resulting from discarded roof shingles during the manufacturing process – can be safely be used in asphalt mixes (Klemens, 1991; Newcomb et al., 1993). Examples of successful implementation of roof shingles recycling programs include the States of Minnesota, Indiana, and New Jersey. In addition, scrap shingle tabs have been successfully used by the private sector in Florida to pave parking lots and to fix potholes. The performance of the material is similar to that of regular asphalt. Soil stabilization characteristics of this material are limited to erosion control. Additional data on the engineering properties of roof shingles can be found in Chapter 5 of this report.

Paper mills in Florida are all located in the northern part of the state, around the Panhandle and Jacksonville areas. There are ten permitted facilities, mostly in Panama City, Jacksonville, and Fernandina, in addition to other smaller mills. There is very little data in the literature on the quantity of **paper mill sludge** generated, but an approximate of the quantity available nationally is estimates at 2 million tons. The quantity generated in Florida is less than 200,000 tons annually. Personal communications also indicate that some amounts of paper mill sludge are burned to generate energy, with the ash generated being landfilled. Paper mill sludge is also being used as a soil fertilizer and compost. While the composition and properties of paper mill sludge may warrant further investigation for use as a binder for base and subbase materials, the geographic distribution and relatively small quantities generated may not warrant widespread uses.

Wood waste in Florida is generally included in the construction and demolition (C&D) waste quantities. Approximately 8% of C&D waste is wood, which amounts to 800,000 tons. The majority of wood waste is either recycled or combusted in WTE facilities. The remaining material can be used where locally available as a temporary lightweight fill material, or for stabilization of temporary access roads. However, the long-term poor engineering properties of untreated wood waste, such as concerns involving decaying of wood, makes it unsuitable for permanent soil stabilization applications.

Large quantities of **quarry waste** are generated in Florida, but the exact quantity is not known. McClellan et al (2002) estimates that the State of Florida will generate 300 million tons of limestone waste between the years 2002 and 2012. The exact breakdown and geographic distribution of all quarry activities is difficult to document because 1) the majority of the waste is re-used in various products such as tile and ceramic production, 2) a large portion goes into roadway base and subbase use (crushed limestone), and 3) there is no single source that identifies the quantity and availability of this type of waste. However, a variety of uses are already taking place in roadway and highway construction.

Other than phosphate, mining activities in Florida are centered around various titanium and iron oxides, and aluminum ores. Two companies based in Starke and Green Cove Springs are responsible for these mining activities and the associated **mine tailings** byproducts. Presently, active mines are located in Bradford, Clay, and Putnam Counties, and small areas in Baker and Duval Counties. Exact quantities of mine tailings in relation to these activities could not be quantified, but the quantities are too small to warrant further study.

Florida's colossal phosphate industry is responsible for the production of 25% of the worldwide production and 75% of the national needs. There are more than 1 billion tons of **phosphogypsum** stored in 25 Florida stacks and 30 million new tons are produced each year. However, phosphogypsum is considered to be a slightly radioactive material by the Florida Department of Environmental Protection, and this has been a major hindrance on finding beneficial reuses for phosphogypsum up to date. If more research is conducted to alleviate or remedy the radiation concerns, the material can be of immense use in FDOT projects.

3.5. Important Environmental Regulations

All of the non-hazardous and hazardous wastes are covered by a set of generic rules issued by the Florida Department of Environmental Protection (FDEP) and published in the Florida Administrative Code (F.A.C.). These rules are developed by the Division of Waste Management (DWM) and range from general rules such as those addressing landfilling and recycling regulations, to specific rules for special materials such as waste tires and incinerator ash.

3.5.1. General Rules

The Solid Waste Management Act is published in Chapter 403, Part IV, of the Florida Statutes (F.S.). The Act provides a definition of what constitutes solid waste, requirements for solid waste management and permitting, regulations for disposal, and provisions for beneficial re-use of such waste. A general set of rules are posted in the Solid Waste Management Rule, Chapter 62-701 of the Florida Administrative Code (F.A.C.). While the rule applies to the management of solid waste in general, it contains some specific requirements that distinguish industrial solid waste from other types of waste.

Hazardous wastes are governed by Rule 62-730, F.A.C., which defines and provides procedures for identifying hazardous wastes. The rule provides standards for transporting, treating, storing and disposing of hazardous wastes.

Permits must be secured for a variety of facilities and activities which are expected to affect the air, water, or land in the State of Florida. For the purposes of this project, only Part II of Rule 62-4, which addresses specific permits, is relevant. Examples include construction permits and monitoring permits that would be required if a recycled material is used in a new roadway application. Rule 62-722 directly addresses the regulation of recovered materials, but again the generator of the material will be impacted by this regulation more than FDOT. A set of specific rules, regulations, and guidelines are available for a limited number of materials and merit further mention.

3.5.2. Industrial Wastes

Section 403.7045(1), F.S. provides an exemption for industrial by-products from regulation as solid waste if the majority of the waste is recycled within one year of production, the material does not pose a threat of contamination in excess of water and air quality standards, and the material is not a hazardous waste. Currently, requirements for storage and disposal of industrial waste are established on a case-by-case basis, with the exception of some C&D waste and incinerator ash which are regulated. Similarly, beneficial re-use decisions are made on a case-by-case basis. This process requires the party requesting re-use of a particular material to provide extensive data and documentation for the proposed activity, which often causes delays in decision making. In June of 2002, permission was granted by the legislature to FDEP to initiate rulemaking efforts for an Industrial Waste Disposal and Reuse (IWDR) rule, and work on the rule was started in 2003. The purpose of the rule is to clarify acceptable practices for the disposal and beneficial use of large volumes of non-hazardous industrial wastes. Work on the rule is still in progress, and no final rule has been issued as of October 2005.

3.5.3. Paper Mill Sludge

In the early 1990s, the Florida Pulp and Paper Association successfully submitted a request based on Rule 62-701.720, F.A.C., which regulates the disposal of industrial solid waste. The request would exempt their industry from disposing paper mill sludge and other pulp and paper waste in Class I Landfills, which are for hazardous waste. The request was supported by data and information to support this action. When new solid waste regulations were promulgated a few years later, the rule on which the request was based was repealed. Currently, FDEP has regulations, with regard to pulp and paper waste, are focused on wastewater regulation. The industry generates ten of millions of gallons of potentially hazardous wastewater that results from the paper processing and bleaching operations. Definite regulations regarding paper mill sludge are currently not available, and beneficial re-use is treated on a case-by-case basis. The proposed new IWDR rule, proposed as Chapter 62-705, F.A.C., will address pulp and paper waste.

3.5.4. Waste Tires

FDEP has a Waste Tire Management Program which includes a regulatory component to regulate the hauling, storage, recycling, and disposal of waste tires. The program also includes a market development component to coordinate efforts with entities interested in beneficial re-use, and a grant program to assist counties in funding their local waste tire management programs. Relevant regulations are posted in the Division of Waste Management (DWM) Waste Tire Rule 62-711, F.A.C.

3.5.5. Incinerator Ash

Section 403.7045(5) of the Florida Statutes allows FDEP to oversee and approve the beneficial re-use of incinerator ash, provided the material is verified to be safe for the environment. To this end, FDEP issued a guidance document for preparing beneficial use demonstrations (BUDs) for municipal incinerator ash (FDEP, 2001). Chapter 62-702, F.A.C., regulates solid waste combustor ash management, and includes provisions for storage and disposal, as well as recycling. As mentioned earlier, there are plans to create a new rule (Chapter 62-705, F.A.C.) to regulate industrial wastes, including WTE ash and coal ash residues; however, the current rule in Chapter 62-702 and the guidance documents for BUDs are in effect until a new rule is issued.

3.5.6. Construction and Demolition Waste

Section 403.707(12)g of the Florida Statues also allows FDEP to oversee and approve the beneficial re-use of C&D waste, provided the safety of the environment is not compromised. As such, FDEP published a set of guidelines pertaining to the so-called Recovered Screen Material (RSM), which encompasses dirt, crushed concrete, drywall and other construction materials screened from processed C&D waste (FDEP, 1998).

3.5.7. Phosphogypsum

Chapter 62-6731, F.A.C., provides regulations regarding the proper management and disposal of phosphogypsum. The rule clearly requires that all phosphogypsum be stored and disposed in phosphogypsum stack systems permitted by FDEP. However, the rule also provides avenues for alternate procedures through a request for exception.

4. Processing and Applications

4.1. Introduction

Although some researchers skip directly from material selection to laboratory and field testing, they miss out on important parameters that more narrowly define and distinguish the materials. As a result, those who wish to validate existing data or build on previous studies are left to their own intuition and deductive reasoning when it comes to reproducing the same material for testing. Two additional parameters should be specified to address the missing links: processing and application.

Processing in this context refers to the preparation, treatment, and conversion of the material from its raw form to a more refined form. Whether the material is processed directly from a parent waste material or collected as a byproduct of external activity, the process spans from origin all the way to use or testing. Application, on the other hand, generically defines how a material will be used in practice or how it is *envisioned* to be used in practice. The envisioned application of a particular material is very difficult to determine from simply reviewing laboratory material parameter tests. The objective is that the material name, its process, and its application will coalesce to rigidly define each recycled material.

4.2. Applications

Past research efforts have examined actual and envisioned applications that range from the mundane and ordinary to truly innovative and specialized. An example of the latter includes the use of tire shreds to mitigate the development of "bumps" at the ends of bridges (Reid et al., 1998). Although some of these specialized applications are mentioned here, they are not included directly within the database framework. Instead, eight general geotechnical and transportation applications were chosen to characterize some of the more mainstream recycled material research. Table 4-1 presents these applications.

Table 4-1: Application Categories

Embankment/Fill	BaseSubbase
Flowable Fill	Stabilized base
Concrete Additive	Soil Reinforcement/Stability
Asphalt Pavement	Other

4.3. Description of Applications

4.3.1. Embankment/Fill

The geotechnical or transportation definition of an embankment is a constructed, raised, earthen mound, composed of soil, aggregate, and other materials. Its purpose is to raise the level of a road relative to the surrounding area (Chesner et al., 2002). Constructed with similar materials, a fill differs in that it is used to cover an area below the surrounding ground surface or to fill in the space behind a retaining wall. Typically, an embankment or fill is composed of several material layers that must simultaneously maximize strength and permeability while minimizing deflection. Because of the large quantities of earthen material required for both embankments and fills, recycled materials offer an attractive, low-cost alternative to expensive borrow material (Vipulanandan and Basheer, 1998). Moreover, recycled materials often exhibit engineering properties that make them more desirable than traditional materials without even accounting for the cost differential. For example, the relatively low unit weight of tire shreds can potentially reduce pressures on retaining walls or lessen the load of an embankment constructed on top of marginal soil.

4.3.2. Flowable Fill

Consisting primarily of fine aggregate, water, and a cementitious component, flowable fill acts as rapidly hardening slurry (Chesner et al., 2002). Its main function is to fill in irregular nonuniform excavations, which require only very low bearing strength. There exists some discrepancy in the literature as to its exact constituent components. However, its formal description as a “controlled low-strength material” that exhibits properties of both concrete and soil-cement is unambiguous (Vipulanandan et al., 1998). Alternate names for flowable fill include lean-mix backfill, flowable mortar, and controlled-density fill (Vipulanandan et al., 1998). Recycled materials are sometimes substituted for traditional fine aggregates such as sand. They may also serve as pozzolanic materials – replacing conventional cementitious components. Pozzolanic is the term given to siliceous materials that exhibit cementitious properties when combined with an activator in the presence of water (Chesner et al. 2002).

4.3.3. Concrete Additive

Portland cement concrete is used in rigid pavements, sidewalks, retaining structures, and bridge components. Made up of coarse and fine aggregate in addition to cement paste, Portland cement concrete also contains cementitious materials and chemical modifiers (Chesner et al., 1998). Recycled materials may be used in place of aggregate or again as pozzolanic cementitious components. The latter is the catalyst through which important physical properties of the concrete can be modified.

4.3.4. Asphalt Pavement

The layers of asphalt, aggregate, binder and other materials that make up asphalt pavement serve as a mechanism to distribute traffic loadings to underlying base and subbase layers. This application encompasses hot and cold mix asphalt as well as surface treatments. Hot and cold mix asphalt differ in both requisite preparation and expected performance. Hot mix asphalt requires the addition of a mineral filler. It must be mixed at a plant, and can be used anywhere while cold mix asphalt can be mixed on site and is only used in lightly-trafficked rural areas (Chesner et al., 2002). Applied as a liquid, surface treatments improve only existing road surfaces. Besides their potential use as substitutes for conventional aggregate in pavements, recycled materials may be used as mineral fillers. The purpose of mineral fillers is to improve stiffening of the hot mix and increase individual particle contact (Chesner et al., 2002). As a result, they establish critical performance characteristics of the asphalt pavement.

4.3.5. Base/ Subbase

Below the asphalt surface layer lie the base and subbase layers of the pavement. Although both are composed of aggregates, the gradation of these aggregates and the function of the two layers allow them to be treated separately. Base layers consist of higher fines content and their purpose is mainly load-bearing and strengthening in nature (Chesner et al., 2002). Located directly below the pavement surface, it must simultaneously promote drainage and dissipate stress to protect the subgrade. The subbase layer is located below the base, and it functions primarily as a foundation. Opportunities for recycled material substitution exist for this application as well. High-strength materials can replace sand and gravel as the principal base and subbase aggregates.

4.3.6. Stabilized Base

Stabilized base is considered a different "class" of base or subbase materials. Similar to the functions of other base layers, its purpose is to improve strength and to more efficiently distribute direct traffic loads to underlying layers (Chesner et al., 2002). The main difference is in composition. A mixture of aggregate, cementitious particles, and water, stabilized base gains strength through compaction. Two terms used interchangeably for stabilized base are soil-cement and roller-compacted concrete. Not surprisingly, recycled materials can be substituted as aggregate or in place of the cementitious particles.

4.3.7. Soil Reinforcement/ Stability

Although not included as a separate application in comprehensive recycled material research efforts, significant data exists pertaining to soil reinforcement and stability. In the past, accepted techniques for dealing with reinforcement of marginal soils included the use of synthetic materials such as geotextiles and geofabrics, chemical stabilizers, and advanced albeit expensive soil improvement procedures such as jet grouting, deep dynamic compaction, and vibroflotation. Homogenous stabilization of these problematic soils can be accomplished by using small strips or fibers of various recycled materials (Consoli et al., 2002; Wang, 1999). Slope stability problems have been solved in the past with the use of soil nailing, micropiles, retaining structures, and shotcrete. However, promising alternatives exist such as improving slope stability with discrete stabilization using waste materials (Loehr and Bowders, 2000). In general, this application follows two main stabilizing mechanisms: discrete and homogeneous stabilization. The former has more to do with stability and the latter with soil reinforcement.

4.3.8. Other

Because of the impossibility of including every possible application for recycled materials either here or as part of the database, it is necessary to provide an "other" category to ensure that even the rarest applications are well documented. Many of these applications are considered specialized applications for specific circumstances and conditions. However, if any one application in this category gains notoriety and becomes the subject of several future research efforts, its status can easily be promoted through the creation of its own category. For current purposes of user access and organization, the "other" category will encompass anything that does not fit into the first seven application categories.

4.4. Processes

Most of the research on recycled materials simply glosses over or completely neglects to mention the material origins and requisite processing. Not only does this practice make duplication of results impossible (since there is no way to ensure that the same material is being tested), but because the process is not described, it is unclear how much expense and time went into processing the material once it has been acquired. Simply put, the breadth of processing techniques is staggering. A process could be as straightforward as stockpiling the material before use or it could be as complicated as a long sequence of treatments requiring several processing machines just to separate the components or refine it. Furthermore, a process dramatically affects the properties that a material will exhibit. This is why a material such as tire chips must be processed differently for use in an embankment than for use in asphalt pavement.

4.5. Material Processing: An Overview

The processing of waste paper and paperboard products is simple. Paper in the form of cardboard boxes, newspapers, magazines, and office paper is recycled through community programs. The paper is collected, sorted, and then shredded before it is used as mulching material and even slick paper hydraulic mulch oversprays (Collins and Ciesielski, 1994).

Unlike paper, plastics originate from a variety of sources and must be processed differently for each application. Table 4-2 shows the six types of plastic resins and their sources. Plastic lumber is formed from reclaimed HDPE, pellets are formed from recycled LDPE and prepared for use as the modifier in asphalt pavement, and a type of polyester is formed from recycled PET to chemically aid in the production of polymer concrete (Collins and Ciesielski, 1994). When used to stabilize cohesionless soils, plastic PET bottles are cleaned, chopped into pieces, and melted in an oven. Afterwards, the filaments are extruded and allowed to cool before they are stretched (Consoli et al., 2002). The mechanism here is homogenous stabilization. Loehr and Bowders (2000) combined recycled plastic, saw dust, and other materials to form composite recycled plastic piles (RPPs) used in discrete stabilization.

Table 4-2: Plastic Resins and their Source

Resin	Name	Source
Low-density polyethylene	LDPE	film/trash bags
Polyvinyl chloride	PVC	pipes/flooring
High-density polyethylene	HDPE	milk jugs
Polypropylene	PP	battery casings/luggage
Polystyrene	PS	egg cartons/cups
Polyethylene terephthalate	PET	soda bottles

MSW incinerator or combustor ash is generated from the combustion of municipal solid waste in one of two types of waste combustors: mass burn facilities or refuse derived-fuel (RDF) facilities (Chesner et al., 2002). The former handles raw solid waste while the latter requires shredded and presorted source materials to ensure the absence of deleterious elements. The resulting ash consists of grate ash, siftings, boiler ash, and baghouse ash; the waste stream may be either combined or separated. The ash that sticks to the grate after combustion is bottom ash whereas boiler ash starts in the primary combustion zone but is later carried into both the gas stream and the pollution control system where it is collected (Chesner et al., 2002).

Scrap tire processing has developed as an industry by itself. Used for everything from tire derived fuel (TDF) and playground surfaces to mulch and aggregate replacement, scrap tires are processed in a variety of ways. Humphrey et al. (1998) suggests shredding whole tires before passing them through a sieve to meet gradation requirements. Several machines are required to process the tires into more refined forms. A cutting machine simply splits tires to form *slit tires* whereas *tire shreds* require a shredder, a machine with reciprocating knives that move forward and back to both tear and cut the tire (Chesner et al., 1998). Because of their small size, *tire chips* (13 to 76 mm) must go through two rounds of shredders, and the secondary shredder reduces the size and increases uniformity in shape. To produce *ground rubber* (0.15 to 19 mm), a granulator or grinding machine is first used to reduce size before exposed steel belts are removed through magnetic separation. Fibers are removed by air separation, and the resulting material is screened and sized (Chesner et al., 1998; Chesner et al., 2002). *Crumb rubber* (0.075 to 4.75 mm) is generated from one of three processes: the crackermill process uses rotating steel drums, the granulator process uses revolving steel plates, and the micro-mill process produces the finest particles (Chesner et al., 1998). Two distinct processing mechanisms are necessary for pavement applications. If used as a substitute for aggregate, *dry* ground rubber is added to the hot mix asphalt. The *wet* process on the other hand, uses crumb rubber as an asphalt modifier to produce rubberized asphalt (Chesner et al., 2002). Figure 4-1 shows a breakdown of scrap tire uses in the US and in Florida.

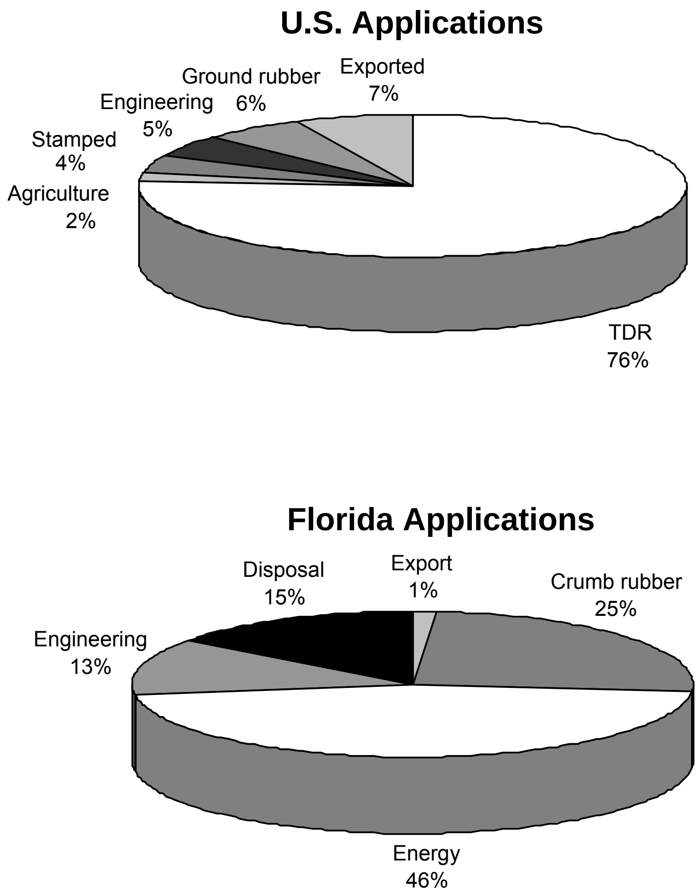

Figure 4-1: Scrap tire use for U.S. and Florida (Liu et al., 2000 and DEP, 2003)

Roof shingle waste originates as prompt shingle scrap (tabs) from shingle manufacturers or as tear-off scrap from contractors. Typically, the material is presorted to remove deleterious materials such as nails, other metal, and wood before it is passed through a processing machine that reduces its size. The final product may resemble anything from 75 mm partial shingle pieces to a much finer, black, soil-like material. In either case, it is important to be aware of risks associated with asbestos contamination. Currently, one of the main processing inconsistencies, which results in varying qualities of final product, has to do with the mixing of raw roof shingles from several sources during collection. Future research may address this issue. When used as an asphalt pavement modifier, prompt shingle waste must first pass through a rotary shredder before its size is reduced further with a high-speed hammermill; then it is stockpiled (Chesner et al., 2002).

Because fly ash has so many engineering applications, care must be taken to process the material appropriately. As a concrete additive, fly ash in dry form is used as a mineral admixture where consistent quality is important (Chesner et al., 2002). As a mineral filler in asphalt pavement, fly ash in dry form is collected and stored. Used as cementitious material in stabilized bases, fly ash takes the place of binder although an activator must be mixed with it to serve as a catalyst for pozzolanic activity (Chesner et al., 2002). In flowable fill applications, fly ash is mixed with sand and/or cementitious material whereas embankment applications only require that it be stockpiled and brought to optimum moisture content before compaction (Chesner et al., 2002; Vipulanandan et al., 1998).

Collected from the bottom of coal-burning furnaces, bottom ash is removed by water jets before "dewatering, crushing, and stockpiling" (Chesner et al., 2002). For asphalt pavement uses, bottom ash and boiler slag are screened and blended with conventional aggregates, and pyrites are removed with electromagnets. Screening, grinding, moisture control, and the removal of contaminants round out the processes required for use in base, stabilized base, and embankment applications of these two materials (Chesner et al., 2002).

In the materials section, the desulfurization process required to produce FGD scrubber base was outlined. In addition to this step, the material must undergo forced oxidation or blowing air into the holding tank to convert $CaSO_3$ to $CaSO_4$ (Chesner et al., 2002). Next the material is subjected to either a centrifuge or a belt filter for dewatering purposes. A dry material is added to stabilize the scrubber before it can be fixated, or modified chemically with quicklime or fly ash (Chesner et al., 2002).

Demolition debris, reclaimed asphalt pavement, and reclaimed concrete pavement are all processed similarly. After C&D waste has been sorted to remove wood, drywall, plastic etc., it is reclaimed and crushed to be used in the place of aggregate (Collins and Ciesielski, 1994). Similarly, RAP and RCA are also crushed, screened, and stockpiled although magnetic separators must be used to remove reinforcing steel in RCA (Chesner et al., 2002).

Blast-furnace slag is crushed and screened to meet gradation requirements, but properties must be tested before use because of inconsistencies in the material (Chesner et al., 2002). As a concrete additive, it must be milled very fine. Steel mill slag must also be crushed and screened prior to use, but other criteria such as moisture content, handling, and hydration expansion must be addressed (Chesner et al., 2002). Similarly, non-ferrous slags are crushed, screened, and blended with traditional aggregate.

Kiln dust is typically used as-is in roadway applications. Mixing small percentages of kiln dust with aggregate and asphalt produces one type of concrete additive. In addition, kiln dusts may be pelletized for use as synthetic aggregate (Chesner et al., 2002).

Waste foundry sand requires crushing, recirculating, and screening to remove large particles. The waste sand is then stockpiled according to particle size (Abichou et al., 1998). Paper mill sludge processing has been the subject of very little research. However, when blended with fly ash, paper mill sludge in the form of bark ash can be fed into coal pulverizers and burned to produce a concrete additive (Collins and Ciesielski, 1994). Wood waste in the form of logging waste and sawdust may be further refined and mixed with other recycled materials to improve their performance. Loehr and Bowders (2000) for example, combined sawdust with plastic to form their recycled plastic piles.

"Hard waste" carpet fibers are added in small doses along with a superplasticizer to improve the toughness of concrete (Wang, 1999). The exact dosage or percentage of fibers to add is still under investigation. In another application, very small dosages of carpet fibers are added to soil to form a homogeneous mixture.

Mill tailings are processed through crushing and separation of ore from the impurities either by media separation, gravity separation, froth flotation, or magnetic separation (Chesner et al., 2002). The key to processing quarry byproducts is blending when they are to be used in base applications and dewatering when they are used as mineral fillers (Chesner et al., 2002). Another mineral byproduct material, phosphogypsum is generated from a wet process in which phosphate rock is dissolved in phosphoric acid. Phosphogypsum is the byproduct and when used as a binder, it requires the use of a vibrating power screen to create uniformity (Chesner et al., 2002).

Waste glass is crushed and screened to reduce size and densify the final product. This is accomplished primarily by several machines including hammermills, rotating breaker bars, breaker plate, and impact crushers (Chesner et al., 2002). In addition to these steps, the processed material must be inspected for metal and paper.

5. Engineering and Environmental Properties

5.1. Introduction

Materials, applications, and processes set the tone for the main item, which is the engineering and environmental properties of the materials. An enormous amount of data is available in the literature and through the additional testing program that was conducted as part of this research project. Detailed reporting of the data is much beyond the scope of the current chapter, and would require a substantial amount of documentation. As such, the vast majority of the detailed engineering properties are included in the recycled materials database. This chapter summarizes only some of the key findings and describes the how data is organized and how the material properties are listed in the database

Obviously the attributes that a material exhibits vary not only with different processing mechanisms but also with material source, manufacturing methods, and method of testing. For this reason, it is essential that the database be replete with as many properties from a breadth of researchers. By considering several different studies of the same material or process, an exhaustive albeit more robust interpretation of that material's "true" behavior surfaces. Another purpose for including properties is to add another dimension for searching and sorting. For example, a user can search for a material knowing only its intended application and required absorption and strength characteristics. In addition to the previously stated reasons, the inclusion of environmental properties allows the user to instantly locate areas of concern. For example, if a processed material has a relatively large concentration of a particular trace metal, monitoring leachate might be necessary. In addition, quality control as well as source and processing mechanism for that particular material must be emphasized.

5.2. Properties

5.2.1. Engineering Properties

After reviewing approximately 90 case studies, it was decided that sixteen engineering properties and nine environmental properties would be considered for the present project. The attributes were chosen both for their ability to comprehensively characterize the materials in terms of their use to stabilize marginal soils, and for their consistent appearance throughout the literature. Obviously, the list is not all-inclusive. In fact, a provision is included for inputting important supplementary properties such as pH, corrosivity, and other parameters that pertain only to certain materials. Again, it must be emphasized that database tables can be easily modified later in order to incorporate more relevant properties. Table 5-1 lists the engineering properties included in the database.

Table 5-1: Database Engineering Properties

Property	**Units**
Unit weight	kg/m2
Specific gravity	
Shape	
Size	mm
Absorption	%
Liquid limit	
Plastic limit	
Classification	
Hardness	Moh
CBR	
Cohesion	kPa
Maximum dry density	kg/m3
Internal friction angle (direct shear or triaxial)	degrees
Optimum water content	%
Compressive strength	kPa
Permeability	cm/sec
Other properties	

5.2.2. Omitted Engineering Properties

While it is true that these properties accurately characterize the materials, several other properties are appropriate, and they have not been considered here. Property data must be entered in table format using numbers or small phrases of text. Although it is possible that "linked objects" can be inserted into a database for the purpose of viewing a figure, such a practice bogs down the database because of the space the object takes up. Moreover, a linked object cannot be indexed and is therefore not searchable. However, additional references to figures and graphs can be included within the appropriate fields in the database. In addition, the user always has the option to look into the data set or case study further by simply accessing its original reference.

5.3. Environmental Properties

The main environmental concerns regarding the beneficial reuse of recycled materials result from the adverse impacts such materials might have on the environment and the human health through direct and indirect exposure. One of the main issues revolving around the present study is the ability to implement the proposed stabilization method in light of FDEP rules. In fact, it has often been the case that a study would be conducted on beneficial re-use of a particular material, only to face difficulties during the implementation phase due to the non-compliance with environmental regulations. Some of the these environmental concerns include the leaching of hazardous constituents from the material into the groundwater, presence of hazardous materials such as asbestos in the material, ignitability and corrosivity of the material, and in some extreme cases, radiation. In the current project, relevant environmental regulations were extensively reviewed, and much of the information was obtained from and reviewed with FDEP personnel.

To elaborate on the effects on human health through direct and indirect exposure, the following examples can be useful. While a sample of incinerator ash may not have any adverse effects on the human health upon direct exposure, the leachate that results upon washing of the material via rain or some other wetting mechanism may have adverse impacts on human health and the environment if the hazardous leachate contaminates the groundwater. On the other hand, a sample of roof shingles that contain asbestos may have an impact on human health upon direct exposure to the material.

Environmental properties also help to characterize recycled materials and determine their eligibility for use in certain applications and regions. Perhaps even more importantly, environmental properties provide useful data for documenting recycled material use and performance – allowing state and federal agencies such as the Florida Department of Environmental Protection (DEP) and the Environmental Protection Agency (EPA) to make informed decisions. Currently, environmental agencies are somewhat reluctant to approve the use of recycled materials without extensive data collection, documented sampling procedures, and an array of quality control measures. As mentioned earlier, materials are often proven to function well from an engineering standpoint, but programs for their implementation become stalled in the environmental approval stage.

5.3.1. Environmental Regulatory Limits

Environmental Protection Agency's (EPA) publication SW-846, titled "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods" is a publication that provides guidelines for the environmental evaluation of solid wastes. This publication outlines several methods that can be used to assess environmental properties, including but not limited to: Toxicity Characteristic Leaching Procedure (TCLP) to test the toxicity characteristics of the leachate produced by the material, ignitability of solids, and corrosivity towards steel as well as the skin.

TCLP testing (EPA Test Method 1311) is one of the most commonly used environmental tests to determine the leaching characteristics of materials. It is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes. The test involves three steps: the separation of the initial solid and liquid phases, the extraction of leachate from the sample through rotary agitation and using the appropriate extraction fluid, and finally the combination of the initial and the final extracts. This combination is then stored and analyzed for various constituents. The concentrations of the constituents need to below predetermined regulatory values for the material to be approved. These regulatory levels for the TCLP test can be seen in Table 5-1.

Table 5-1. EPA Toxicity Characteristic Leaching Procedure (TCLP) Limits

Constituent	**Regulatory Limit (mg/L)**
Arsenic	5
Barium	100
Benzene	0.5
Cadmium	1
Carbon Tetrachloride	0.5
Chlorobenzene	100
Chloroform	6
Chromium	5
Cresol	200.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
2,4-D	10
,4-Dichlorobenzene	7.5
,2-Dichloroethane	0.5
4-Dichloroethene	0.7
2,4-Dinitrotulane	0.1
Endrin	0.02
Heptachlor (and its epoxide)	0.008
Hexachlorobenzene	0.1
Hexachloro- 1 ,3-butadine	0.5
Hexachlorothane	3
Lead	5
Lindane	0.4
Mercury	0.2
Methoxychlor	10
Methyl Ethyl Ketone	200
Nitrobenzene	2
Pentachlorophenol	100
Pyridine	5
Selenium	1
Silver	5
Tetrachloroethene	0.7
Toxaphene	0.5
Trichloroethene	0.5
2,3 ,5-Trichlorophenol	400
2,4,6-Trichlorophenol	2
2,4,5-TP	1
Vinyl Chloride	0.2

The Synthetic Precipitation Leaching Procedure (SPLP) is another commonly used standard test for leachate generation, and is less aggressive than the TCLP in terms of stripping the material of solidified hazardous substances. The procedure utilizes acetic or nitric acid as the extraction agent, and is viewed as a less conservative alternative to TCLP, but also a better simulator of ambient environmental conditions.

For Florida, it is also important that these concentrations meet the Maximum Contaminant Levels (MCL) established with EPA's National Primary Drinking Water Regulations, as well as the Soil Cleanup Target Levels established by the FDEP. These regulatory values are presented in Appendix II and Appendix III, respectively.

Ignitability of Solids (EPA Test Method 1030), Corrosivity Toward Steel (EPA Test Method 1110A), and Dermal Corrosion (EPA Test Method 1120) are also common tests used to determine various characteristics of solid wastes such as the ignitability potential and corrosion potential towards steel and skin. However, these tests are somewhat more specialized than TCLP, and results of these tests for the materials on hand were not investigated for this report due to their specialized nature.

Another popular environmental test is the Total Trace Metals Test. There are various EPA methods for this test, and the appropriate one should be chosen depending on the nature of the sample being tested. The 3000-series test methods section of the EPA SW-846 outlines the various test methods available. This test serves to determine the total concentration of the metals of importance in the material. If a total analysis of the waste demonstrates that individual analytes are not present in the waste, or that they are present but at such low concentrations that the appropriate regulatory levels could not possibly be exceeded, the TCLP need not be run, as per EPA SW-846. Therefore, running this relatively simple and inexpensive test could save time and money by helping to avoid the time consuming and expensive TCLP test. The EPA regulatory limits for this test can be seen in Table 5-2.

Table 5-2. EPA Total Trace Metal Limits

Constituent	**Regulatory Limit (mg/kg)**
Silver (Ag)	2,000
Arsenic (As)	1,000,000
Barium (Ba)	2,500
Beryllium (Be)	1,000,000
Cadmium (Cd)	1,000,000
Cobalt (Co)	1,000,000
Chromium (Cr)	1,000,000
Copper (Cu)	1,000,000
Molybdenum (Mo)	1,000,000
Nickel (Ni)	1,000,000
Lead (Pb)	200,000
Antimony (Sb)	200,000
Selenium (Se)	1,000,000
Thallium (Tl)	1,000,000
Vanadium (V)	1,000,000
Zinc (Zn)	1,000,000

There are also additional tests that may need to be performed depending on the nature of the material. For instance, if the material is believed to contain asbestos, then a test such as the Polarized Light Microscopy (PLM) test may be required. If radiation is believed to be a problem, radiation monitoring devices may need to be used to determine the level of radiation emitted by the materials. Other environmental criteria, such as incremental risk index for carcinogens and hazard index for non-carcinogens may also need to be determined through various other tests. Therefore, the tests that may need to be performed are in no way limited to the ones mentioned in this report.

Kim (2003) summarized the parameters and properties associated with the use of recycled materials, that are of environmental concern to most regulators. Table 5-3 summarizes such concerns by providing common trends among regulatory agencies, but it is in no way exhaustive. Many of these concerns are addressed through data collection in the database.

Table 5-3: Properties of Environmental Concern (Kim, 2003)

Parameter	Potential Hazardous Property	Affected
Leachable trace metals	As, Cd, Cu, Cr, Hg, Pb, Zn	Ground/surface water
Leachable organics	Benzenes, phenols, corrosivity, pH	Ground/surface water
Soluble solids	Soluble and mobile salts	Groundwater
Total respirable dust	Respirable fine particles	Air
Trace metals in dust	Respirable or deposited trace metals	Air/secondary
Trace organics in dust	Respirable or deposited trace organics	Air/secondary
Volatile metals	As, Hg, Cd, Pb, Zn released at high temp.	Worker health
Volatile organics	Chlorinated hydrocarbons released	Worker health

5.3.2. Organization and Input

With the above information in mind, the recycled materials database is equipped with environmental data from a variety of both laboratory case studies and field case studies. It is organized into four tables in the database, but the end user need not be familiar with such database organization. Table 5-4 contains the table names and their corresponding fields.

Table 5-4. Environmental properties in the recycled materials database

Chemical Composition
Chemical composition
Weight percentage
Metal Concentration
Metal name
Concentration (mg/L)
Concentration (mg/kg)
Organic Concentration
Organic compound
Class
Concentration (mg/L)
Concentration (mg/kg)
Leachate
Constituent
TCLP (mg/L)
SPLP (mg/L)
EPTox (mg/L)
ASTM D-3987 (mg/L)

In the chemical composition data, chemical compounds are defined to correspond to a unique case study and process combination. For example, a study by Jenkins that examines the use of reclaimed asphalt pavement in base and subbase applications might have several chemical compounds and weight percentage values associated with it. The importance of linking this database table to both the Performance (case study) table and the Process table is apparent. Each time a material goes through a refining process to produce a usable material, both engineering and environmental properties have the potential to change. Also, different researchers have documented varying chemical compounds and weight percentages of those compounds in their case studies. Therefore, each time data is examined from the Chemical Composition table, the user is aware that the information is specific to *one particular* researcher and *one particular* process. Not surprisingly, over 500 records currently exist in this table.

The Metal Concentration table has one main purpose – to identify and quantify the existence of trace metals within a processed material. Similar to the Chemical Composition table, it is linked to both the Performance table and the Process table. Therefore, data in this table corresponds to a unique case study and processed material. For example, scrap tires envisioned and processed for use as embankment or fill in a study by a particular researcher might include concentrations of aluminum, lead, and any other metal. The presence of certain metals in high concentrations precludes their use in several applications.

The Organic Concentration table is mainly concerned with the presence of various classes of organic compounds (i.e. volatiles, semi-volatiles, phenols etc.) that are components of processed recycled materials. Special areas of concern include organic compounds such as benzenes, phenols, and vinyl chloride that impact both groundwater and surface water quality (Chesner et al., 2002). Each record in the database corresponds to a specific case study and process. A study by Freeman, which analyzes the suitability of fly ash as flowable fill might have anywhere from ten to thirty entries for organic compounds and their concentration values in mg/L.

The final environmental properties table, Leachate, warrants special consideration as there are several different tests used to measure this parameter. Many of these tests developed as a result of the Resource Conservation and Recovery Act (RCRA) that was passed by Congress in 1976.

It dealt with hazardous waste disposal and environmental management of waste. These tests fit into one category of leachate tests: *regulatory methods*. The other two categories are *standard methods* such as those specified by organizations including ASTM and *research methods*, developed to measure specific and unique properties (Kim, 2003). Leaching is defined as the removal of materials by dissolving them away from solids. All four tests included as part of the database are batch tests – tests involving a given volume of leachant solution such as water for a given period of exposure time. The four tests are summarized in the Table 5-5.

Table 5-5: Regulatory Methods Tests (Kim, 2003)

Method	Leachant	Sample size (g)	pH	L/S	Units	Time (hr)
TCLP	Acetic acid or acetate buffer	100	2.88	20	mg/L	18
SPLP	Water w/ nitric and sulfuric acid	100	4.2	20	mg/L	18
EPTox	Water	100	5.0	20	mg/L	24
ASTM	Water	70		20	mg/kg	18

One important point that has developed over the recent years is the comparison of these tests in terms of statistical reproducibility and accuracy as compared to some standard "true value." Kim (2003) argues that exact duplication of regulatory or standard methods is impossible among various laboratories. In fact, there is only a 60 to 80 percent probability that tests conducted by different laboratories with the same protocol will exhibit similar results (Kim, 2003). While this aspect of statistical variability has not been included in the current project and database efforts, it is to be kept in mind while interpreting or promoting particular methodologies.

Table 5-5 also provides the truncated abbreviations of the regulatory leaching batch tests. The full names are as follows: Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP), Extraction Procedure Toxicity Test (EPTox), and Standard Test Method for Shake Extraction of Solid Waste with Water (ASTM-D3987). In addition to the differences shown in the table among the tests, TCLP and SPLP warrant further explanation. As mentioned earlier, TCLP is an EPA analytical method designed to simulate leaching of contaminants in landfills similar facilities. Its main purpose is to characterize a waste material as hazardous or non-hazardous. SPLP, on the other hand, is an EPA analytical method designed to simulate acid rain effects. Specifically, it is concerned with toxic organic and inorganic soil contaminants that migrate into the groundwater table (Aerotech, 2004).

5.3.3. Data Range

Some research studies are numerically and test-intensive. A study may contain data from the testing of twenty materials with only a few samples from each material or it may contain data from testing only one material with twenty samples. In either case, a decision must be made as to which data should be entered into the recycled materials database. For engineering properties, and in order to record the relevant parameters *from that particular study*, each parameter is assigned four fields: high, low, mean, and standard deviation. Thus, rather than a collection of isolated information from tests, the database contains a data range. Certainly some element of subjectivity must enter into the database design stage and the data entry stage. In both engineering and environmental testing, statistical outliers are discarded. Although it is possible that these outliers represent valid data, in most instances, such data is usually the result of contaminated samples and/or poor testing protocol.

Environmental tests do not include provisions for entering a data range. Instead, an average value (mean) and a standard deviation are calculated from each testing category after discarding the outliers. For example, a TCLP test performed ten times for one processed material may include one result that is significantly removed from the other nine values. As a result, the mean and standard deviation are recorded for the nine values and then entered into the database.

5.4. Evaluating Performance

An exhaustive review of current and past research on recycled materials was conducted in an attempt to fill the database with as much useful information as possible. In addition, laboratory testing was conducted on selected materials to complement and verify the existing information, and to provide additional data to evaluate particular materials of interest. While it is task-extensive to completely characterize each material in this document, an overview of the materials is definitely appropriate. Detailed information and data on each of the materials is appropriately included in the recycled materials database. In the sections that follow, some of the materials are examined in detail and a discussion of general performance, field use, limitations, and special considerations are also included. Perhaps this section can be viewed as a sort of comparison and summary of findings. A detailed summary of the feasibility, concerns, and main conclusions regarding each material is provided in a table format at the end of this report (Chapter 8).

5.4.1. Plastics

Surprisingly, out of the three previous efforts at a recycled materials comprehensive compendium, only one included any information on plastics. This is probably due to the fact that it is a relatively new material in the arena of geotechnical and transportation applications. As stated earlier, plastics are used in at least two stabilizing mechanisms: discrete and homogenous. Consoli et al. (2002) examine sand reinforced with strips of recycled, processed, plastic strips. Long, flat strips of varying length are added either alone or in combination with Portland cement in small doses to increase strength and stiffness of loose sand. The plastic strips improved both peak and ultimate strength in both cases. The *plastic waste* exhibited the following engineering properties (Consoli et al., 2002):

- specific gravity = 1.06
- internal friction angle between 37º and 43º
- tensile strength between 207 and 230 MN/m^2
- elastic modulus of 7 GN/m^2.

Loehr and Bowders (2000) explore weak reinforcement of slopes with recycled plastic piles. In the field study, 317 of the piles are eventually installed with a continuous monitoring system so far proving the plastic piles' efficacy. The following values were reported by Loehr and Bowders (2000):

- compressive strengths = 21000 kPa
- tensile strength = 13000 kPa
- cost = $42 per square meter of slope face.

So far, it appears that plastics are used in only a few applications – slope stability and soil reinforcement. To be used properly it is important to specify the type of plastic (i.e. PET fibers or HDPE pellets etc.).

On the other hand, little environmental data is available on this material, perhaps due to the wide discrepancies among the different resins (polymers). Another possible explanation for the lack of environmental data on plastics is the generally accepted notion that most recycled plastics are environmentally stable and do not leach harmful substances into the environment. In fact, the most commonly recycled plastics are few, with the most popular types being Type 1 (Polyethylene Terephthalate, PET) and Type 2 (High-Density Polyethylene, HDPE). These types are generally harmless to the environment and currently get recycled and beneficially reused in many applications including plastic lumber.

However, other types of plastics may still pose threats to the environment. Amongst the materials used in the plastics industry for which special care should be taken are lead salts, phenol, aromatic hydrocarbons, isocyanates and aromatic amines. In many plastics articles, these toxic materials are only used in trace doses. However, if such materials leach, they can create a potentially hazardous condition (Brydson, 1999). Therefore, great care should be taken to ensure that plastics containing such materials do not find their way into the ground to be used in geotechnical applications. This can only be assured through extensive testing, and quality control and assurance by the suppliers providing these plastics.

5.4.2. Scrap Tires

Scrap tires have easily generated the most recent research interest for their wide availability, consistent recycling practice, potential applications, consistent engineering properties, and relatively low-impact environmental properties. In fact, few ASTM standards have already been established on the proper reuse of recycled scrap tires. The one best suited for geotechnical applications is ASTM D6270-98, titled "Standard Practice for Use of Scrap Tires in Civil Engineering Applications" (ASTM, 1998). Although the use of scrap tires in field projects has been widespread with some 40 state highway agencies conducting some sort of research, its use is still deemed experimental. This is due to several factors including high upfront costs (investment in processing machines and monitoring equipment), the necessity of monitoring performance and maintenance requirements over a long period of time, and the evolving mandates and environmental guidelines involving the use of scrap tires. Tire chips have been investigated for use in embankments and fill (Bosscher et al., 1997; Humphrey et al., 1998;

Vipulanandan and Basheer, 1998) in asphalt pavement applications (Chesner et al, 2002), in specialty applications (Reid et al, 1998), and their impact on the environment has been assessed (Chesner et al, 1998; O'Shaughnessy and Garga, 2000; Liu et al., 2000).

The following range of engineering properties has been observed for scrap tires:

- unit weight of 390 to 584 kg/m^3 depending on void ratio
- specific gravity of 1.1 to 1.3
- absorption of 2 to 3.8%
- cohesion of 8 to 12 kPa
- internal friction of 19º to 41º depending on whether shreds, chips, or crumb rubber is used
- permeability of 1.5 to 15 cm/sec
- heating value of 28000 to 35000 kJ/kg
- Young's modulus of 770 to 1250 kPa.

The reasons for the relatively wide ranges of properties stem from the use of varying sizes and shapes of scrap tires. In general, crumb rubber, the smallest processed scrap tire material, has a higher unit weight, higher friction, and lower permeability precisely because there is less void space.

The large variation in processing techniques and machinery has been addressed in a previous section. However, two environmental studies warrant special consideration. O'Shaughnessy and Garga (2000) examined the leaching behavior of an embankment constructed with scrap tires. The research, a combination field and laboratory study, found almost no evidence of either metals or organics exceeding local regulatory limits. Some "anomalies" existed including the presence of selenium in concentrations that slightly exceeded limits and inconsistencies in long-term results associated with concentrations of lead, cadmium, and chromium (O'Shaughnessy and Garga, 2000). However, the difficulty is in sorting and comparing such results to similar studies that cite conflicting data.

A study by Liu et al. (2000) also evaluated the environmental characteristics of scrap tire embankments through an original effort and comparison with previous studies. The study found that the control sample, typical bituminous asphalt actually leached higher concentrations of metals than the sample containing scrap tires (Liu et al., 2000). In addition, none of the laboratory samples containing scrap tires exceeded allowable limits for TCLP tests and EPTox tests (Liu et al., 2000). Table 5-6 summarizes their findings.

Table 5-6: Scrap Tire Leachate Summary (Liu et al., 2000)

Metal	**Minn. pH 3.5**	**Minn. pH 5**	**Minn. pH 7**	**Minn. pH 8**	**Wisconsin AFS**	**Tire Mgmt. Council**	**VDOT, long-term**
Al							0.746
As						ND	
Ba	0.488	0.205	0.174	0.265	0.12	0.59	2.08
Cd	0.125	0.007	0.005	0.005		ND	0.004
Cr	0.235	0.002	0.005	0.002	0.003	0.05	0.082
Cu							0.328
Fe	500	41.2	0.531	0.718	0.23		31.62
Pd	0.417	0.051	0.038	0.039	0.015	0.016	0.138
Mn					0.3		
Hg						0.0004	
Ni							2.46
Se	0.203	0.054	0.045	0.028	0.005	ND	
Ag							0.005
Zn	23.5	17.5	3.38	0.005	0.63		0.153

Scrap tire field implementations have gained notoriety for recent failures and therefore warrant special consideration. In 1995, two scrap tire road embankments in Washington State and one in Colorado began to exhibit signs of exothermic reactions – heat is released as a result of chemical or biochemical reactions (Liu et al., 2000). This led researchers to examine the causes and propose solutions. All three of the field embankments/fills were constructed *exclusively* with scrap tires, and the tire shreds had exposed steel belts (O'Shaughnessy and Garga, 2000). According to researchers, "the potential causes of initial exothermic reaction are oxidation of exposed steel wires, oxidation of rubber, microbes consuming exposed steel wires or generating acidic conditions, and microbes consuming liquid petroleum products" (O'Shaughnessy and Garga, 2000). The existence of free oxygen was a result of inadequate soil cover or exposure to fertilizer-rich soil or crumb rubber. As a result of these experiences, guidelines for embankment construction using scrap tires are now available.

When mixed with soil, scrap tires are known to reduce the unit weight, therefore warranting their use in lightweight fill. In fact, experimental data obtained as part of the current study indicate a reduction in maximum dry density of as much as 1% for every 1% of waste tires by weight included in the mix (Figure 5-1). These results, however, indicate a slight decrease in LBR associated with such inclusion of shredded tires in the soil mix.

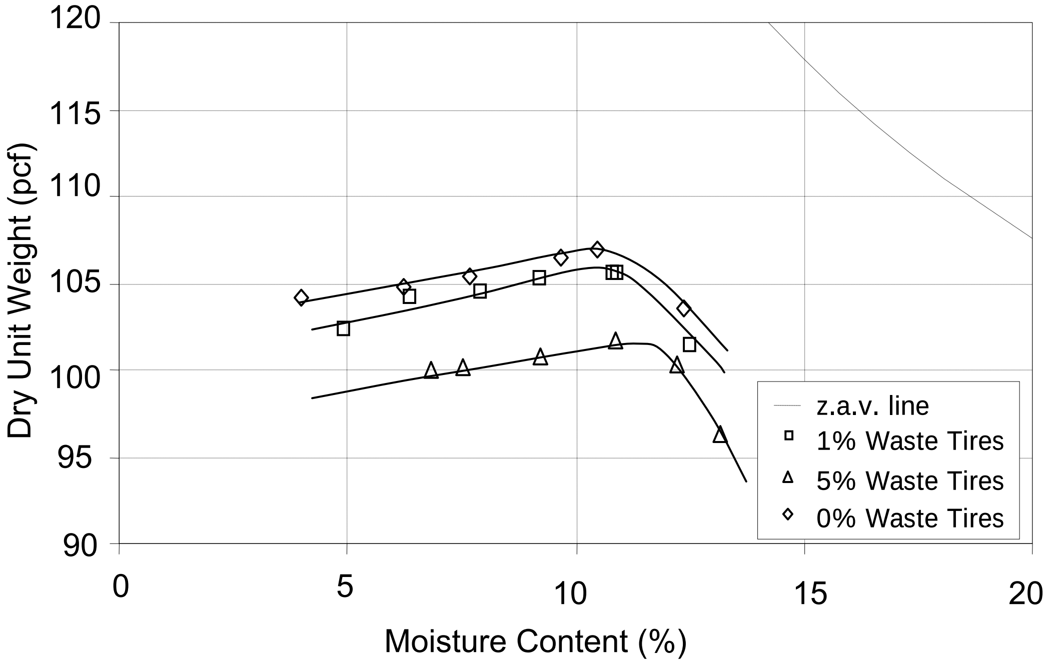

Figure 5-1. Modified Proctor tests conducted on Florida sand (A-3) mixed with waste tire shreds.

Tire shred leaching characteristics have been examined under a wide range of pH conditions. Under neutral pH (pH=7) normally encountered in surface flow-through applications, iron and manganese levels increase as these metals are extracted from any exposed tire reinforcing wire. However, both metals are generally present in soils, and the increases are generally not considered to be harmful to people or the environment. The rate of dissolution of wire increases under acidic conditions (pH < 7), and zinc present within surface rubber can also be leached, but levels generally remain within acceptable parameters. Under basic conditions (pH>7), organic compounds can be leached in trace quantities.

As a result of this data, tire chips are recommended for use in flow-through applications above the water table to minimize long-term leaching exposure and in relatively neutral natural conditions. Extensive practical experience with such applications has confirmed the absence of any deleterious impact. Many state regulatory agencies have historically limited the use of waste tire chips to applications above the mean high water table. However, recent studies of experimental applications below the water table have shown little or no impact in downstream water quality (Hammer and Gray, 2004). Leaching data can be found in Section X1.9 of ASTM D6270-98.

5.4.3. Waste Glass

Waste glass was investigated for use in asphalt pavement, base, and embankment applications (Chesner et al., 2002; Collins and Ciesielski, 1994). Most glass recycling occurs through individual household sorting before it goes to material recovery facilities to further separate and grind it down. Attention must be given to specifications that limit impurities such as ceramics, ferrous metal, paper, and plastics. Such impurities negate the otherwise uniform properties that clean glass exhibits. The finished product can be processed to decrease both size and angularity make it suitable for additional applications.

The following engineering properties were observed for waste glass:

- unit weight of 1120 to 1900 kg/m^3
- specific gravity of 1.96 to 2.52
- hardness = 6
- CBR of 42 to 132
- maximum dry density = 1900 kg/m^3
- optimum water content of 5.7% to 7.5%
- internal friction angle of 51º to 53º
- coefficient of permeability of 0.06 to 0.2 cm/sec
- abrasion = 36%

A previous study conducted by the Clean Washington Center (CWC) in 1993 analyzed aqueous crushed glass samples for biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), pH, specific conductivity, priority pollutant metals and cobalt using the sequential batch extraction method outlined in ASTM D 4793 (Cosentino et al., 1995). The concentrations recorded for these tests appeared to be below regulatory limits. The results are presented in Appendix IV.

Additional lead tests were also conducted by CWC following completion of the above-mentioned tests to obtain a larger statistical sampling on the incidence of lead contamination. The results showed that presence of lead over regulatory limits was possible, probably due to lead foil wine neck wraps that are crushed along with the glass (Soil & Environmental Engineers, Inc., 1998). Therefore, testing for lead content is recommended for all waste glass recycling companies. The waste glass was also analyzed to determine the effects of working with glass cullet on human health. The detected values for these tests were below regulatory limits.

Additional leaching studies have been conducted by the Florida Institute of Technology in 1995. These studies were conducted using column extraction method (ASTM D 3987) instead of using sequential batch extraction method used by CWC. Three different column heights were tested for materials obtained from two different sources, Brevard Shredded Mixed Glass (BSMG) and West Palm Beach Material Recycling Facility (WPBMRF). The tests showed that waste glass is contaminated with soluble organics and capable of producing a leachate with high BOD and Total Khejdal Nitrogen (TKN) concentrations. This study also stated that waste glass may become clean due to rainfall and biodegradation during its accumulation and storage at the solid waste handling facility (Cosentino et al., 1995). Therefore, it is imperative that glass be properly washed and decontaminated by the provider before any use in roadway construction.

5.4.4. Carpet Fibers

In general, carpet fibers performed inadequately when used for soil stabilization. They were proven to perform better as concrete reinforcement when added is small percentages. However, improvement in flexural strength and toughness came at the expense of compressive strength. As soil reinforcement, carpet fibers are impractical especially in sandy soils where they tend to migrate to the surface (Wang, 1999). Also, even when mixed in concrete, a superplasticizer is required to increase workability to an acceptable level (Wang, 1999). Researchers have had bad experiences with carpet fibers, and their poor engineering properties and limited availability make them an undesirable recycled material. For the purpose of documentation, the following engineering properties were observed for soil mixed with carpet fibers: unit weight of 1724 kg/m^3, optimum water content of 16.5%.

5.4.5. Incinerator Ash

Incinerator ash has been used in asphalt concrete and in base and subbase applications. It has been used in Chicago, Houston, Washington, D.C., and smaller locales in Pennsylvania and Massachusetts – all in asphalt pavement applications and most as a replacement for coarse aggregate in asphalt paving mixes. Concerns have been raised over leaching of heavy metal such as lead and cadmium since past efforts have seen amounts in excess of regulatory limits (Collins and Ciesielski, 1994). In general, EPA has been slow to approve incinerator ash as a construction material, and has even characterized it as a boredeline hazardous waste in some instances. Many of these problems stem from the inconsistency of the processed material itself. The material may be processed in a mass burn facility (no presorting) or a refuse derived-fuel facility (requires presorting), and this facility may be new or old.

Engineering properties of incinerator ash are very favorable, with a low unit weight and high strength characteristics, as follows:

- unit weight of 965 to 1290 kg/m^3
- specific gravity of 1.86 to 2.24
- CBR of 95 to 190
- friction angle of 40º to 45º
- LA abrasion of 44 to 50%
- absorption of 3.6 to 14.8%
- maximum dry density of 1730 kg/m^3

One of the main characteristics of incinerator ash is that it forms into lumps due to the pozzolanic action of its components. In order to breakdown the lumped ash, samples were placed and grinded in Los Angeles Abrasion test to simulate moderate breakage activities in the field. The dry sieving method as outlined in the ASTM standard (ASTM D-422) was then adopted for the particle size distribution analysis. Figure 5-2 shows a typical grain size distribution curve of incinerator ash obtained from the Pasco County landfill.

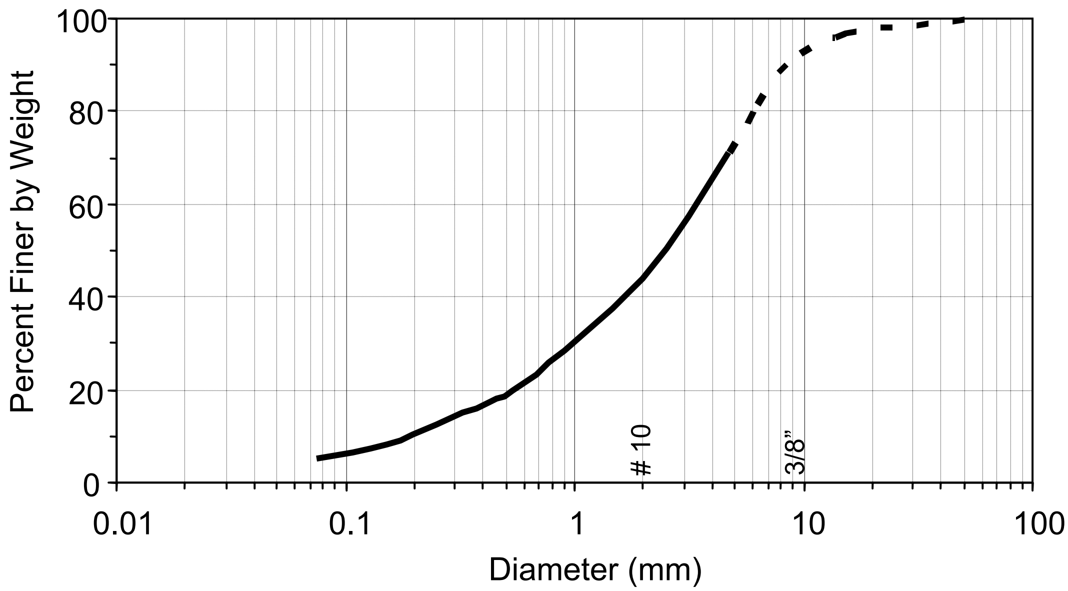

Figure 5-2: Grain size distribution curve of incinerator ash from Pasco County landfill.

The compaction properties of uniform soil mixed with incinerator ash are very favorable. Figure 5-3 shows the Proctor curves of uniform Florida sand (A-3) mixed in varying proportions with incinerator ash. The mixing can serve the dual purpose of 1) reducing the concentration of ash and thus the potential for leachate contamination, and 2) allow the use of incinerator ash on numerous projects, since the relatively small quantities generated do not warrant continued and sustained use of ash-only on FDOT projects.

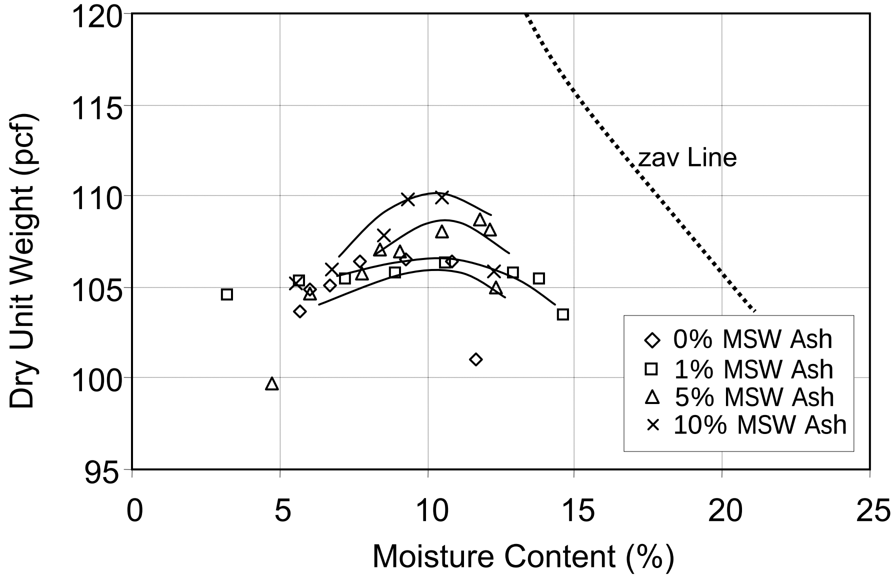

Figure 5-3: Compaction curves of uniform Florida sand (A-3) mixed in varying proportions with incinerator ash.

As a result of the variation in ash processing methods, and due to the variability over time of the parent materials, the quality of the final processed ash may be inconsistent and may exhibit varying environmental properties. As such, periodic testing and environmental monitoring is recommended. For Florida incinerator ash, one favorable data trend can be found in a study done by the Florida Department of Environmental Protection (FDEP) for the 2001-2002 Solid Waste Annual Report. The study, performed following best available practices, yielded favorable TCLP results for the 13 Waste-to-Energy (WTE) facilities located in Florida. The results showed no signs of hazardous leachates from the incinerator ash produced in these facilities. The results can be seen in Table 5-7.

Table 5-7: TCLP results for incinerator ash from Florida's WTE facilities

FACILITY NAME	Arsenic *(mg/l)*	Barium *(mg/l)*	Cadmium *(mg/l)*	Chromium *(mg/l)*	Lead *(mg/l)*	Mercury *(mg/l)*	Selenium *(mg/l)*	Silver *(mg/l)*
Montenay, Bay WTE	0.173	1.000	0.252	0.500	0.646	0.100	0.035	0.173
Dade County	0.050	0.603	0.375	0.061	3.980	0.000	0.032	0.010
North Broward WTE	0.080	0.370	0.018	0.020	0.090	0.007	0.190	0.028
South Broward WTE	0.089	0.589	0.004	0.022	0.247	0.009	0.222	0.009
Hillsborough County WTE	0.020	0.390	0.396	0.015	0.370	0.001	0.040	0.004
Hillsborough County WTE	0.020	0.430	0.393	0.012	0.140	0.001	0.040	0.004
Lake County WTE	0.022	0.720	0.004	0.013	0.100	0.001	0.040	0.004
Lee County WTE	0.022	0.956	0.172	0.019	0.090	0.001	0.040	0.004
McKay Bay WTE	0.141	0.437	0.017	0.018	0.142	0.000	0.050	0.065
Palm Beach County WTE	0.018	2.836	0.087	0.028	0.537	0.000	0.000	0.000
Palm Beach County WTE	0.024	3.918	0.006	0.030	0.193	0.000	0.010	0.005
Pinellas County WTE	0.243	0.152	0.364	0.020	0.065	0.000	0.143	0.067
Southern Most WTE	0.500	1.017	0.159	0.500	1.055	0.100	0.100	0.500
Regulatory Threshold (40CFR 261.24)	5.000	100.000	1.000	5.000	5.000	0.200	1.000	5.000

Note : 90% Upper Confidence Interval for 14 samples over a seven day period; SW 846 -Test Method 1311.

While these results are well below the regulatory limit, there are still variances from facility to facility. This is due to the fact that different facilities (except those operated by the same company) have different methods for treating the incinerator ash. For beneficial reuse applications, it is important that such variances be minimized as much as possible so that uniform incinerator ash can be obtained from each facility. To address this, FDEP has produced a publication titled "Guidance for Preparing Municipal Waste-to-Energy Ash Beneficial Reuse Demonstration". As cited earlier in Section 3.5 of the report, this publication provides guidelines for the necessary steps that need to be taken to prepare an acceptable beneficial reuse demonstration for incinerator ash, as well as stating the general environmental criteria that need to be satisfied for incinerator ash. When providing such a demonstration, the beneficial reuse demonstrations must consider human exposure pathways such as inhalation, ingestion, and dermal contact with the ash in its proposed use (FDEP, 2001).

5.4.6. Coal Byproducts (Fly Ash, Bottom Ash, Boiler Slag)

Fly ash can be used as flowable fill, as a concrete additive, in asphalt pavement, and in stabilized bases or embankments. Due to its pozzolanic properties, or tendency to form cementitious compounds, when combined with calcium and water, it can be adapted to various conditions. Also, it is an abundant recycled material, and a large percentage is actually put to use in FDOT-related activities. In general, fly ash has proven to be a versatile material, and it has performed well is the vast majority of these applications. However, as has been mentioned in a previous section, the class and quality of fly ash varies. Depending on the type of parent coal (bituminous, sub-bituminous, and lignite) that is burned, the class (Class-C or Class-F), and other processing mechanisms and technology, the properties of fly ash, especially the environmental ones can vary dramatically. The range of both engineering and environmental properties is too great to include here, but it is included in the database.

Bottom ash and boiler slag are generally not investigated individually, but rather they are included as part of combined studies. Unlike fly ash, these materials do not exhibit pozzolanic properties, but they are still used in asphalt pavement, base, subbase, and stabilized base applications. Like fly ash, the majority of bottom ash and boiler slag is used in construction and roadway activities. The engineering and environmental properties vary with the type of parent coal as well as the processing technique. An element of concern is the possible corrosive properties of these materials as a result of the salt content and low pH of both bottom ash and boiler slag. As such, corrosion potential should be investigated prior to use. The following engineering properties were observed for coal byproducts:

- unit weight of 720 to 1620 kg/m^3
- specific gravity of 2.1 to 2.89
- absorption of 0.8% to 7.52%
- LBR of 50 to 85
- internal friction of 34º to 55º
- permeability of 0.001 to 0.1 cm/sec
- LA abrasion of 35% to 43%
- void ratio of 0.49 to 0.53

The broad range of values of the various parameters suggests the necessity of material testing prior to use or source control.

5.4.7. Scrubber Base

Flue gas desulfurization (FGD) sludge, or scrubber base, has been investigated for potential use in stabilized base and embankment applications. Field implementation has taken place in Kentucky and Pennsylvania sites (embankments), Louisiana (road shoulders), and Texas (stabilized base). It is important to differentiate between different forms of FGD scrubber base. The product may be in an unoxidized calcium sulfite form, which can be used for roads or it may be in an oxidized calcium sulfate form, which can be used as a concrete additive (Chesner et al., 2002). In its unoxidized state, FGD scrubber can be further subdivided by whether it has been dewatered, stabilized, or fixated. Not surprisingly, engineering properties are widely scattered. Currently, close to 95% of scrubber base is beneficially re-used in Florida in applications including gypsum and wallboard production, and cement and concrete production.

5.4.8. Slags (Blast-furnace, Steel-mill, Non-ferrous)

Historically, it has been difficult to gather accurate information on the various types of slags. Researchers have often failed to divide the slags into subcategories before summarizing data. In addition, non-ferrous slags are almost always grouped into one category even though they exhibit very different properties based on their parent ore (i.e. copper, nickel, zinc, phosphorus, lead etc.). Blast-furnace slag can be air-cooled, granulated, or expanded, and it can be used in asphalt pavement, base, embankments, or as a concrete additive (Collins and Ciesielski, 1994). Steel slags are produced from one of three types of furnaces: open hearth, basic oxygen, and electric arc and can be used in asphalt or base applications (Chesner et al., 2002; Collins and Ciesielski, 1994). In general, these slags are heavier than traditional aggregate materials, and they are hard, stable, and resistant to abrasion (Collins and Ciesielski, 1994). Used in asphalt pavement, embankment, and base applications, non-ferrous slags exhibit varying properties according to their parent ore and whether they have been air-cooled or granulated (Collins and Ciesielski, 1994). Their use has been limited relative to the other types of slag. As mentioned in Section

3.4.2, all slags are either being beneficially re-used or come in too small a quantity to warrant further investigation. In terms of the suitability of the engineering properties for usage in roadway applications, steel slag is known to be a highly expansive material, which is highly unfavorable.

For documentation purposes, the following engineering properties have been observed for blast-furnace slags:

- unit weight of 800 to 1940 kg/m^3
- specific gravity of 2 to 2.7
- absorption of 1% to 6%
- hardness of 5.5 to 6
- CBR of 250
- internal friction angle of 40º to 45º
- LA abrasion of 40%

The following engineering properties have been observed for Steel-mill slags:

- unit weight of 1600 to 1920 kg/m^3
- specific gravity of 3.2 to 3.6
- absorption of 3%
- hardness of 7
- CBR of 300
- internal friction angle of 40º to 50º
- LA abrasion of 23%
- pH above 11 (contributes to corrosive properties)

The following engineering properties have been observed for Non-ferrous slags:

- unit weight of 1360 to 3800 kg/m^3
- specific gravity of 2.8 to 3.8
- absorption of 0.13% to 5%
- hardness of 7
- internal friction angle of 40º to 53º
- LA abrasion of 26%.

5.4.9. Kiln Dusts (Cement and Lime)

Kiln dusts have been investigated essentially from a field implementation standpoint (Collins and Ciesielski, 1994), and were found to perform poorly. The principal uses are in asphalt pavement and stabilized base applications (Chesner et al., 2002). In addition to the poor performance of these materials, there is some question as to the underlying processing mechanism. As mentioned earlier in the report the cement industry in Florida has moved to a self-contained dry kiln systems, where the cement/lime kiln dust produced during the process gets reintroduced into the system. This system prevents the production of any waste material. Small amounts of cement/lime kiln dust are left over from the old kiln systems; however, issues such as limited availability, the high pH content of this waste material and the high transport costs associated with hauling the material from its original source onto the actual job sites make this material undesirable for beneficial re-use purposes.

5.4.10. Demolition Waste

Investigated for its use in asphalt pavement and base/subbase applications, C&D waste provides another interesting albeit inconsistent recycled material. The material is essentially a mix of wood, plaster, concrete, glass, metal, brick, shingles, and asphalt. Because of the variation in both quality and percentage of these components and because the components themselves were manufactured differently, it is difficult to control the material to meet gradation or construction performance requirements. Once the material is sorted and screened, specific uses for the specific components, including roof singles and crushed concrete, can be outlined. Again, the quality control responsibility must lie with the material provider such as the manufacturer or the recycling facility. The existence of both sewage sludge and asbestos is a very real possibility which precludes the use of the material unless safeguards are put in place by the material provider. The presence of such deleterious materials must be investigated and their absence must be ensured prior to incorporation into road applications.

5.4.11. Reclaimed Asphalt Pavement and Reclaimed Concrete Pavement

Reclaimed asphalt pavement (RAP) has been investigated for use in hot and cold mix asphalt pavement as well as base, stabilized base, and embankment applications. The research is clear that reuse of this material is approaching 100 percent, and the portion that goes unused each year is usually stockpiled and used the following year. Performance and implementation programs have followed suit, and as a result processing capabilities are well-developed. One problem with RAP is its inconsistency. Specifically, RAP is a product of constituent materials such as asphalt type, and stockpiles can often be contaminated with foreign soils and debris. Also, the parent pavements themselves vary in quality depending on how many times they were resurfaced or patched. So it is that quality control must be maintained preferably at a local level to ensure uniformity in material properties. A comprehensive evaluation of recycled asphalt pavement (RAP) and its uses in roadway construction was recently conducted for FDOT by the Florida Institute of Technology (Cosentino and Kalajian, 2001; Cosentino et al., 2003). A detailed study of reclaimed concrete aggregate (RCA) was performed for FDOT by Kuo et al. (2001).

Reclaimed concrete aggregate does not enjoy the same widespread use as reclaimed asphalt pavement at the national level. However, re-use capacity in Florida is currently approaching 100%. Reclaimed concrete aggregate, or RCA, is used as a concrete additive and in base and embankment applications. As is the case with other materials, RCA will produce consistent properties if it is well-processed and it comes from a consistent source. Problems arise from the use of recycled concrete from various sources. Aggregates from the concrete in footings and piles can contain foreign substances as compared to pavement concrete. Also, different concrete types yield a product that has varying aggregate quality, size, and compressive strength. Finally, salty environments such as Florida's are responsible for exposure of the parent concrete to high levels of chlorides.

The following engineering properties were observed for reclaimed asphalt pavement:

- unit weight of 1600 to 2300 kg/m^3
- LBR of 25 to 180 (the large range is attributed to reasons mentioned above)

- maximum dry density of 1872 to 2000 kg/m^3
- optimum water content of 5% to 8%

The following properties have been observed for reclaimed concrete aggregate:

- specific gravity of 2 to 2.5
- absorption of 4% to 8%
- LBR of 120 to 180
- maximum dry density of 1984 kg/m^3
- optimum water content of 7.5%
- internal friction angle of 40º

5.4.12. Roof Shingles

As a material that has been studied much less than some of the others, recycled roof shingles could prove its value if certain limitations can be addressed. As stated in the materials section, two types of roofing shingle byproduct exist: prompt roofing shingle scrap (leftover from the manufacturing of roof shingles) and tear-off roof shingles (leftover from replacement of roofs by contractors). Both the engineering and environmental properties of prompt roofing shingle scrap are fairly consistent, which facilitates their incorporation into civil engineering applications. However, tear-off roof shingles may contain deleterious materials such as nails, insulation, metal, wood, water proofing components, and in some cases asbestos. In addition, the asphalt cement binder component of this type of scrap is usually old and weathered. Field implementation has occurred mainly in the form of cold-patching of antiquated pavement sections in low traffic areas.

To evaluate the geotechnical properties of such material, several samples of pulverized roof shingles were obtained from a recycling facility in Tampa. Grain size distribution curves for and compaction curves for the same material mixed with uniform Florida sand (A-3) are shown in Figures 5-4 and 5-5. It is evident from the compaction curves that no specific improvement is gained from the use of such material as a stabilizer for uniform sand.

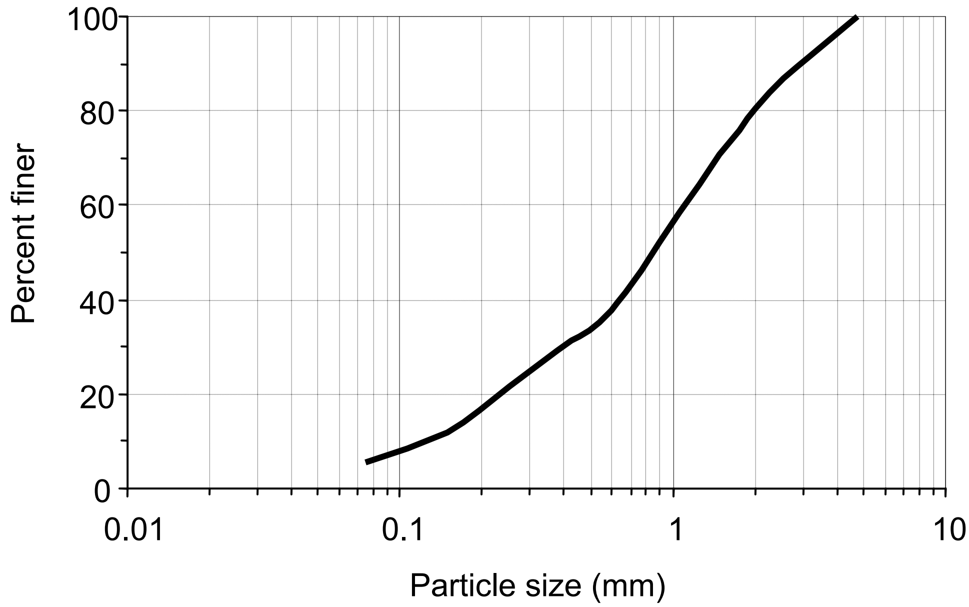

Figure 5-4: Grain size distribution of pulverized roof shingles

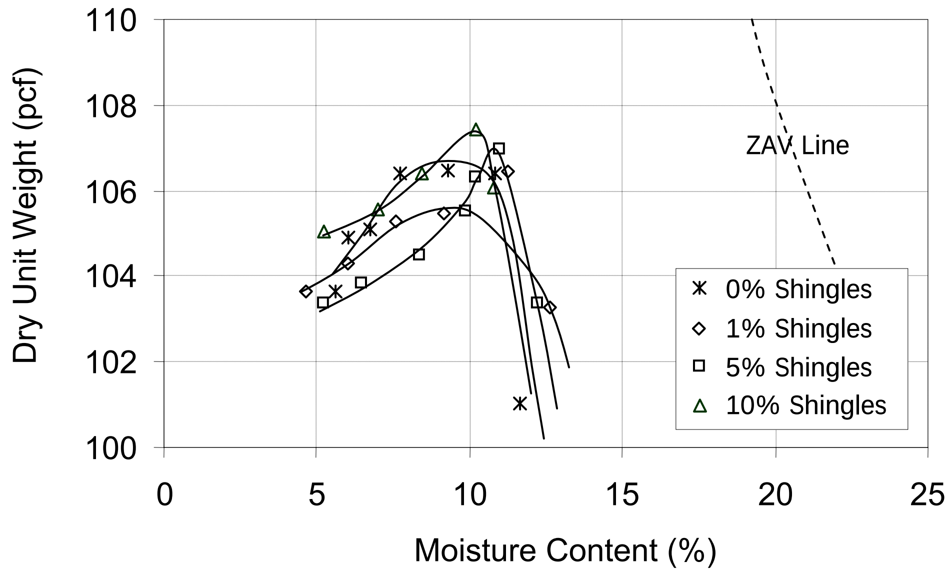

Figure 5-5: Compaction curves of uniform Florida sand (A-3) mixed with pulverized roof shingles in various proportions.

The material, if consistent in properties and if quality control can be provided to ensure environmental safety, can be used as part of an asphalt mix for roadway surfacing. The material has been used to pave and patch parking lots in Florida. However, the widespread use of the material for such purposes must be tied with a comprehensive testing program to evaluate its engineering properties when mixed with asphalt.

Among the main environmental concern with scrap roof shingles is the potential presence of asbestos in tear-off singles. As per EPA, roofing is considered an asbestos containing material if it contains greater than 1 % asbestos. In the initial Asbestos NESHAP rule promulgated in 1973, a distinction was made between building materials that would readily release asbestos fibers when damaged or disturbed and those materials that were unlikely to result in significant fiber release. The terms “friable” and “non-friable” were used to make this distinction. To this end, friable asbestos-containing material (ACM) is defined by the Asbestos NESHAP, as any material containing more than one percent (1%) asbestos as determined using Polarized Light Microscopy (PLM), that, when dry, can be crumbled, pulverized or reduced to powder by hand pressure. EPA has since determined that, if severely damaged, otherwise non-friable materials can release significant amounts of asbestos fibers.

A recent study by the Resource Management Group (2001) provides valuable information about the asbestos content of scrap roof shingles in Florida. A three phase sampling procedure was conducted on scrap roof shingles, and the samples were tested for their asbestos content using Polarized Light Microscopy (PLM). The results are presented in Table 5-8. It can be seen from the results that asbestos was indeed present in some samples above regulatory levels, albeit within the mastic (binder) and paint in almost all cases. However, the mere presence of asbestos above the regulatory limits makes it impossible to secure FDEP approval for use. Leaching studies conducted on scrap roof shingles in the literature consistently show no constituents over the regulatory TCLP limits.

Table 5-8: Summary of PLM results showing asbestos content of studied roof shingles in Florida

Project Phase	**Number of Samples**	**Number of asbestos-contaminated samples (above regulatory limit)**
First Processing Phase	92	5 (3 in mastic)
Second Processing Phase	17	0
Third Processing Phase	482	1 (in roof paint)

In order to evaluate the engineering properties of soil-shingle mixes in more detail, a series of direct shear tests and creep tests were performed. The results from the direct shear test (Fig. 5-6) indicate that no significant benefit is derived from the addition of pulverized roof shingles to sand. To the contrary, the test data indicate that a strength reduction may occur at high normal stresses when roof shingles are mixed with A-3 sand.

In addition, an experiment was performed where either sand or pulverized roof shingles were compacted in a modified Proctor mold, then loaded under constant nominal loads of 45 and 125 lbs using the conventional LBR piston in order to evaluate the long-term deformation (creep) behavior of both material. The results shown in Fig. 5-7 indicate that pulverized roof shingles undergo significant creep deformation compared to sand, which is an unfavorable property with respect to base and subbase materials.

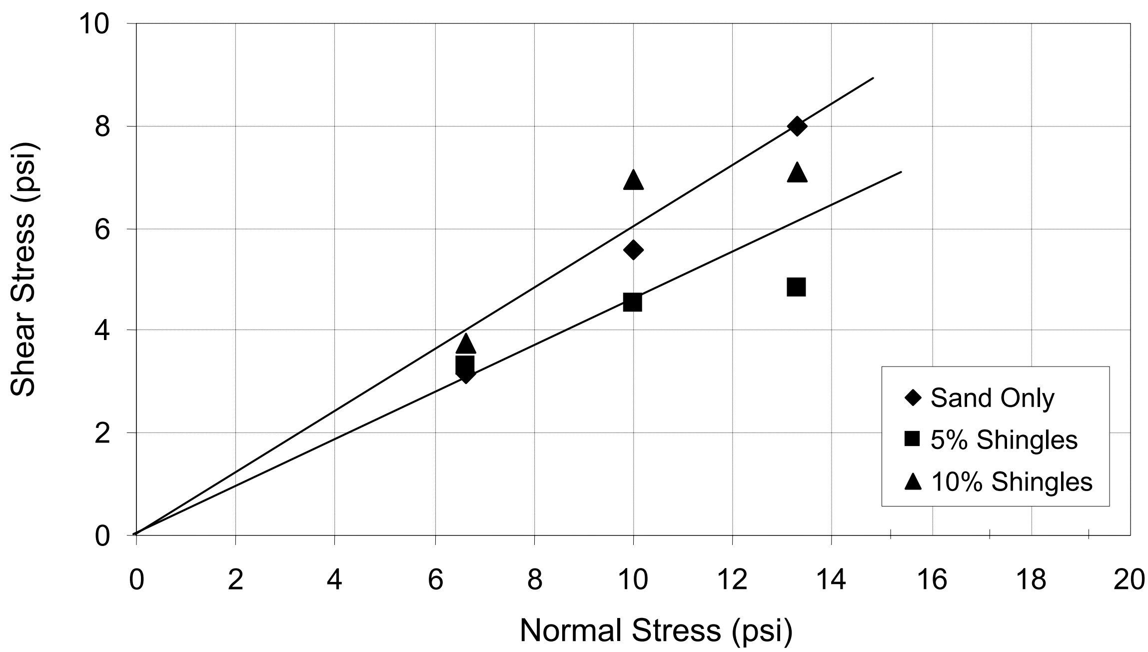

Figure 5-6: Results of direct shear tests on uniform Florida sand (A-3) mixed with pulverized roof shingles in various proportions.

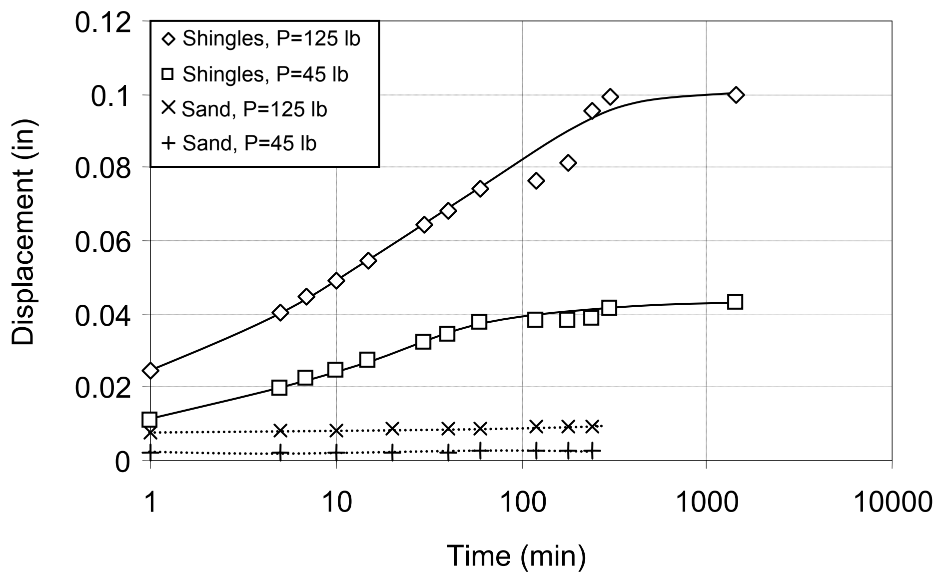

Figure 5-7: Creep behavior of pulverized roof shingles and sand under constant load.

The important consideration is that if recycled roof shingles are to be used, the source must be controlled to ensure that no asbestos is present in the final product. Whether this happens through the exclusive use of prompt roofing shingle scrap or if it happens through presorting and control on the part of the material supplier/recycler, the issue must be addressed. In addition, the engineering properties of scrap roof shingles warrant the use of the material only in asphalt pavements, not as a marginal soil stabilizer.

5.4.13. Foundry Waste

Foundry waste has been used in asphalt pavement applications and flowable fill. Edil and Benson (1998) and Abichou et al. (1998) investigated the use of waste foundry sand as hydraulic fill. The presence of up to 15% bentonite reduces the hydraulic conductivity dramatically (Edil and Benson, 1998). Additionally, waste foundry sand performed satisfactorily when it was used to construct embankments (Mast and Fox, 1998). Foundry waste incorporates furnace dust, arc furnace dust, and residue in addition to foundry sand. Special consideration must be given to the presence of large concentrations of trace metals in foundry dusts. Foundry sand is a better alternative due to its greater availability and its status as a non-hazardous material. Even so, attention must be paid to contaminants such as stone and trash as well as to its fine, uniform gradation and leaching of some heavy metals and phenols (Collins and Ciesielski, 1994). Depending on the foundry source, high concentrations of cadmium, lead, copper, nickel, and zinc are also possible.

The lack of adequate quantities of foundry sand in Florida does not warrant any further investigation of the material. Nevertheless, for documentation purposes, the following engineering properties are reported for foundry sand:

- unit weight of 2590 kg/m^3
- specific gravity of 2.39 to 2.6
- absorption of 0.42 to 0.46%
- liquid limit of 31
- plastic limit of 25
- CBR of 4 to 20
- cohesion of 7 kPa to 15 kPa
- internal friction angle of 33º to 40º
- maximum dry density of 1855 kg/m^3
- optimum water content of 0.1% to 10%

5.4.14. Paper Mill Sludge

Very little information is available on paper mill sludge. In the literature, it has been cited almost exclusively as a potential cover material for landfills (e.g., Quiroz and Zimmie, 1998). Its use was tested as a substitute for traditional landfill cover materials such as clays. It exhibits unique properties such as high water contents, low to medium organic contents, low shear strengths, and high compressibility (Quiroz and Zimmie, 1998). Hydraulic conductivity is the design parameter of interest, and it is this value that decreases while shear strength increases as the material consolidates. To ensure smooth construction, low pressure equipment must be used to place and compact the sludge. In addition, researchers have pointed to the need to establish some mechanism of quality assurance since the paper mill sludge byproduct is sensitive to both paper production changes and changes in wastewater treatment processes. Another byproduct of the paper industry, spent sulfite liquor may have potential for soil stabilization as an aggregate binder. The following engineering properties were observed for paper mill sludge:

- specific gravity of 1.88 to 1.96
- liquid limit of 285
- plastic limit of 94
- compression index of 1.24
- extremely low permeability values, typically less than 10^{-8} cm/s

The material contains high percentages of kaolinite and other clay minerals, and indeed behaves as a low to high plasticity clay, which precludes its use in conventional roadway construction applications. Modified Proctor tests were conducted on uniform Florida sand (A-3) mixed with varying percentages of paper mill sludge obtained from a facility in north Florida. The tests indicate that the maximum dry density of the soil decreased as a function of increased sludge content (Figure 5-8). More importantly, the optimum moisture content increased dramatically in conjunction with this increase in sludge content. This is undesirable in most roadway applications, although the use of the material may be possible as an aggregate binder. Data available in the literature overwhelmingly indicates that the shear strength of paper mill sludge is extremely low.

From an environmental standpoint, paper mill sludge is a complex and changeable mixture of dozens or even hundreds of compounds, just like paper mill waste water. Some are well known, like heavy metals, dioxin and other organochlorines. Some, created by the bacteria in the treatment ponds, are probably harder to define. Potential leaching of heavy metals into the ground, as well as the affects of bioaerosols on the environment and the human health, are the main concerns with paper mill sludge, and the EPA has considered listing paper mill sludge as hazardous waste. Because the composition of paper mill sludge can be highly variable, representative TCLP results could not be provided for this material. However, as previously mentioned, this byproduct has a high potential to leach hazardous constituents. In addition, the engineering properties do not appear to be favorable as indicated by the high plasticity and low shear strength of the material. Therefore care should be taken in considering it for beneficial reuse.

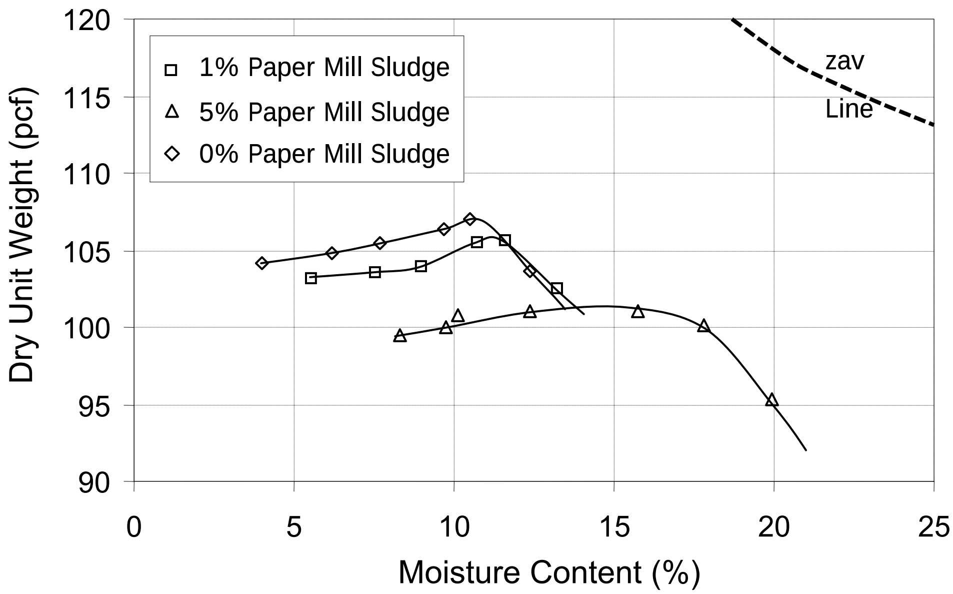

Figure 5-8. Modified Proctor test results on uniform sand (A-3) mixed with paper mill sludge.

5.4.15. <u>Quarry Waste</u>

Quarry waste consists of screenings, settling pond fines, and baghouse fines. It has been used as cement additives, and in asphalt pavement and flowable fill in Florida, as well as Georgia, Illinois, and Missouri among others. There is no single set of properties or guidelines that can be cited for quarry waste as it varies considerably depending on the source and aggregate type. Local officials can be assured of consistent engineering and environmental quarries only within the same quarry location.

5.4.16. <u>Mine Tailings</u>

In relation to many of the materials, mine or mill tailings are extraordinarily abundant. As fine-grained waste from ore concentration processes, mill tailings are produced from the concentration of metals and other elements such as copper, iron, lead, and zinc. Nationally, they have been used in asphalt pavement, base/subbase applications, and as embankment and fill materials. In Florida, there are a few mining activities that are overshadowed by the colossal nature of the phosphate industry. For example, Florida is the only state that produces rutile (titanium oxide) and staurolite (iron aluminum silicate hydroxide). It also is one of the main producers of ilmenite (iron titanium oxide), and zirconium. In the past, a number of heavy minerals have been mined all around the state, but presently, the industry is carrying on mining activities only in Bradford, Clay, and Putnam Counties, and to a smaller scale in Baker and Duval Counties.

Unfortunately, properties, especially grain-size distribution vary dramatically with methods of ore processing, percentage of solids in the slurry, and location of the material within the same tailing pond. Other problems include high impurity content, metal leachability, and acidity or low pH levels of the leachates. For documentation purposes, the following engineering properties were observed for mine tailings:

- unit weight of 1600 to 2300 kg/m^3
- specific gravity of 2.6 to 3.5
- maximum dry density of 2025 kg/m^3
- optimum water content of 10% to 18%
- internal friction angle of 28º to 45º
- coefficient of permeability of 0.01 to 0.0001 cm/sec

5.4.17. Phosphogypsum

Phosphogypsum is a controversial material that has been investigated extensively in the past but is currently only cited in passing in the literature. As a local material, phosphogypsum stacks can be found almost exclusively in Florida. However, due to a 1989 EPA ban on the use of phosphogypsum, research has slowed dramatically. As a result, special provisions must be made to FDEP and EPA before this material can be used. Despite all this, experimental sections of phosphogypsum stabilized roads are still performing well in Florida and Texas. In the past, most construction difficulties were a result of excessive moisture, overstabilization, and poor mixing and sealing.

The future of phosphogypsum as a viable recycled material is questionable, mainly due to the current environmental regulations, which cite levels of uranium-226 and radium that are 10 times and 60 times the background concentrations in soil, respectively. When radium-226 decays, it produces Radon-222, a gas that may diffuse into the air and pose health hazards. A 1992 study by the EPA concluded that while risks to current users and exposed population groups generally would be acceptable, future risks to persons who might live in homes eventually built on abandoned agricultural or road-bed lands containing or constructed with phosphogypsum would be unacceptable (Batelle Pacific Northwest Laboratories, 1996). However, some believed that EPA's assumptions were overly conservative and that the results might be different with more reasonable assumptions. A 1996 study done by the Batelle Pacific Northwest Laboratories (PNL) for Florida Institute of Phosphate Research (FIPR) set out to review these assumptions and the EPA background document. The study concluded that the results obtained in the PNL study and the EPA study were similar except for the direct gamma radiation levels, which the PNL study determined to be lower compared to the EPA study (Batelle Pacific Northwest Laboratories, 1996). A leaching study on raw phosphogypsum was conducted by Taha and Seals (1992a). The range of values obtained from the tests show that arsenic, cadmium, lead, and selenium may leach more than the regulatory limits.

The following engineering properties have been cited in the literature for phosphogypsum:

- unit weight of 1470 to 1670 kg/m^3
- specific gravity of 2.3 to 2.5
- cohesion of 75 to 180 kPa
- internal friction of 28º to 47º
- maximum dry density of 1670 kg/m^3
- optimum water content of 13% to 18%
- variable compressive strength, depending on water content

6. Economic Aspects

6.1. Cost Evaluation

6.1.1. Overview

Quantifying the cost of recycled materials is a very difficult issue to address. This is the result of several factors. First, as a general observation, very little information is available regarding the cost of most recycled materials, which are cited in the literature. Researchers are much more concerned with evaluating engineering performance and even environmental impact of the materials rather than developing cost comparisons. Another problem with costs associated with waste materials is that they constantly fluctuate and change consistently over time. Over time, new taxes, environmental fines, restrictions, and inflation all have a progressive effect on costs. In addition, costs change as a result of improvements in recycling processes and variations in market conditions. For example, twenty years ago, very few tire-recycling firms ever existed. As of the beginning of 2004 however, some 41 tire recycling facilities are located in Florida alone (FDEP, 2003). The increase in firm competitiveness and productivity has driven down both direct and indirect costs. Another problem with quantifying costs stems from the large discrepancies in waste material cost and availability on both a national and a local level. Transport costs and premium costs associated with limited material availability can be greatly affected. Finally, cost analysis sometimes takes into account more subjective criterion such as cost to landfill and cost to the environment if the materials are not reused. In short, cost is difficult to quantify for researchers, engineering professionals, and database designers.

6.1.2. Considerations

Comparison is a key issue in recycled material research. Waste materials must be compared to the traditional materials that they are replacing, and waste materials must be compared to each other. Perhaps the first consideration for the use of any material is adequate engineering performance. If the waste material functions adequately in the specified application, it can at least be considered for potential use. However, once this criterion has been met, the cost of the recycled material must be compared to established materials such as select fill, aggregate, etc. It is difficult to make the case for using a particular recycled material if the costs associated with it are higher than those of accepted materials. One possible exception occurs when materials are mandated for use through government legislation or bureaucratic regulation. In this case, cost is barely a consideration. However, this case will not be addressed here. Instead, recycled materials will be examined theoretically from a comprehensive consideration of all cost components.

6.2. Cost Breakdown

Although very few researchers have addressed cost in investigating the use of recycled materials, Chesner et al. (2002) develops cost considerations by borrowing from the economics of manufacturing. Specifically, three components are examined: cost of the material, cost of installation, and life-cycle cost. For the purpose of the current study, a fourth cost, environmental cost, should also be considered in the analysis.

6.2.1. Material Cost

The material cost is associated with what the buyer – in this case the engineering firm, contractor, or agency would pay to have the material on site and available for use. The seller would be the material supplier, recycling firm, or material handler. Equation 1 is proposed by Chesner et al. (2002) to express material cost:

$$C_{DP} = P_{RM} + C_{PR} + C_{ST} + C_{LD} + C_{TR} + P \qquad (Eq. 1)$$

where,

C_{DP} = Delivered price

P_{RM} = Raw material price

C_{PR} = Processing cost

C_{ST} = Stockpiling cost

C_{LD} = Loading cost

C_{TR} = Transporting cost

P = Profit

It must be emphasized that the components of the equation are necessary only when there exists a significant difference in the cost in comparison to similar costs associated with traditional materials. For example, transporting may be necessary for select fill as well as for scrap tires. However, due to the large void ratio of scrap tires in relation to select fill, more truckloads may be required thereby increasing the cost.

Transporting, loading, and stockpiling costs are all self-explanatory. However, it must be mentioned that the raw material price can essentially have a positive or negative value. In general, if a recycler or processing firm sells the material, the raw material price will be positive, whereas if a manufacturing plant or production facility must otherwise dispose of the waste material for a fee, the raw material price will be negative (Chesner et al., 2002). Processing costs are those associated with refining a waste material so that it can be used. This involves shredding, crushing, screening, presorting etc. Processing costs are extremely variable depending on the material that is processed, processing requirements, and establishment of the recycling market. For example, economies of scale allow shredded tires to be produced at a lower per unit cost than several other materials that require markedly less processing. Profit is also highly variable.

6.2.2. Installation Cost

The engineering firm or contractor may plan to subcontract the installation out or they may be interested in potential incurred costs as a result of installation. In addition, some materials require monitoring of both engineering systems and environmental impact. Some pre-testing of the material might also be necessary. Chesner et al. (2002) proposes Equation 2 to address such costs. Again, these component costs are only taken into account when there is a significant difference between the recycled material and the material for which it is substituting:

$$C_I = C_{DR} + C_C + T_{RP} \qquad (Eq.\ 2)$$

where,

C_I = Installation cost

C_{DR} = Design cost

C_C = Construction cost

T_{RP} = Testing/inspection cost

6.2.3. Life-Cycle Cost

To further the comparison, it is important to consider the effect that the use of a recycled material in lieu of an established material has on maintenance or upkeep. This borrows from the economics of manufacturing in which the cost of a new machine must be compared to an older machine requiring yearly maintenance. Equation 3 proposed by Chesner et al. (2002) is basically an equivalent annuity calculated from a combination of maintenance costs, interest rates, and product life:

$$A_{EC} = C_I \times CRF(i,n) + C_{AM} \qquad (Eq.\ 3)$$

where,

A_{EC} = Annual effective cost

C_I = Installation cost (Eq. 2)

CRF(i,n) = Capital recovery factor (percent interest, i, and product life, n)

C_{AM} = Annual maintenance cost

Life-cycle cost is only an issue when recycled material use results in additional requirements in terms of maintenance and repair. For example, an asphalt pavement road may require supplementary maintenance techniques in addition to more regular servicing.

6.2.4. Environmental Cost

Although not included in the preceding cost analysis, environmental cost is very real and must be included for the sake of completeness. Unfortunately, environmental cost is much more esoteric – requiring subjective evaluation. It includes the potential environmental costs associated with not using a particular material. It might also include costs associated with mandated environmental cleanup as well as costs required to deal with problems of rapidly-filling landfills. The following equation is presented here to deal with this cost:

$$C_{EV} = C_{ES} + C_{EL} / n - C_{ER} \qquad (Eq. 4)$$

where,

C_{EV} = Short term environmental cost, which may include permits and environmental treatment

C_{EL} = Long term environmental cost, which includes insurance and potential cleanup costs

n = Product life or duration over which the responsible party is liable for cleanup

C_{ER} = Environmental cost savings incurred from recovery and re-use of the material

6.3. Database and Cost

From the database standpoint, it is not advisable to include cost as simply a total cost associated with the material. With the current database design, it is proposed to include the cost in addition to the year in which the cost data or quote was obtained. Other suggestions include providing a local or source-specific framework in which to view the evolution of cost over time and by region.

7. Relational Database Design

As was mentioned previously, a recycled materials database was developed in conjunction with this project. A new recycled materials database, which is currently being developed at the University of South Florida separately from this project, includes many of the features of the current database, but is friendlier to the user. Relevant sources of research in the databases including technical reports, archived publications, online resources, books, special publications, conference proceedings, as well as data collected during the course of this project, were categorized and documented. This step served the dual purposes of supplying substance for the database and highlighting areas in need of further research. A commercially-available software, Microsoft Access® is used as the database management system (DBMS).

7.1. Identification of Tables and Fields

Although table organization and corresponding field headings are assigned at the discretion of the database designer, certain obvious choices exist. There is a table dedicated to the 24 recycled materials as well as one for their potential applications and one for the processing mechanisms and techniques that generate a usable product. In addition, tables exist for each of the following: performance (case study), case/process (engineering properties), chemical composition, metallic concentration, organic concentration, and leachate analysis. Some tables such as the Performance table serve as intermediate tables – linking the primary tables while simultaneously providing compulsory information, which in this case includes authors names, literature reference, and the state and year in which the research was performed.

The Materials table contains fields corresponding to the material's name, description, and availability. Consistent with each of the nine tables, there exists a field, IDMaterial, which is a unique numerical identifier, or primary key, to be used when generating relationships among tables. As mentioned previously, the primary key or ID is data type "autonumber," which increments automatically each time a new record is created. Each primary key field corresponds to at least one field of similar name that functions as a secondary or foreign key. Primary and foreign keys directly link two data tables together and indirectly link the entire set of tables into one continuous, organized compendium. In addition, the key fields establish the requisite relationships between tables and fields. A portion of the Material table is reproduced in Figure 7-1.

MATERIALS : Table

MaterialName	IDMaterial
Paper	1
Plastics	2
Incinerator Ash (MSW)	3
Scrap Tires	4
Roof Shingles	5
Fly Ash (Coal Ash)	6
Bottom Ash (Coal)	7
Scrubber Base (Coal)	8
Demolition Debris	9
Blast-Furnace Slag	10
Steel Mill Slag	11
Non-Ferrous Slag	12
Cement/Lime Kiln Dust	13
Reclaimed Asphalt Pavement	14
Reclaimed Concrete Pavement	15
Foundry Wastes	16
Paper Mill Sludge	17
Wood Waste	18
Carpet Fibers	19
Mine Tailings	20
Phosphogypsum	21
Quarry Waste	22
Glass	23
Boiler Slag (Coal)	24
	(AutoNumber)

Record: 11 of 24

Figure 7-1: Part of the Material Table

The Application table is composed of application titles and their descriptions. Like the Materials table, it has a primary key, IDApplication, which links it to the rest of the database. The Process table contains one primary key, IDProcess, and two foreign keys: IDMaterial and IDApplication in addition to a process description field and a cost per ton field. The IDProcess automatically increments each time a new, unique material/application combination is entered. The Performance table has one primary key, IDCaseStudy that uniquely identifies each case study and one foreign key, IDProcess. This table contains requisite fields to comprehensively cite each case study: Authors, Reference, Year, State, and a brief SummaryMemo that summarizes the purpose and findings of the research effort. The Case/Process table contains one primary key, IDCaseProcess that identifies each unique combination of a specific process (material and application combination) and a specific case study. It also contains two foreign keys: IDProcess and IDCaseStudy. This table also encompasses eighteen fields corresponding to eighteen engineering properties. The majority of engineering properties have a "high" field and a "low" field – allowing the user to enter a range of data values. The Chemical Composition table contains a chemical compound name, a foreign key (IDCaseProcess), and a field in which to cite the chemical compound's weight percentage. Similarly, the Metal Concentration table, the Organic Concentration table, and the Leachate table all share the same foreign key, IDCaseProcess. However, the Organic Concentration table also has fields for class (i.e. volatiles, semivolatiles etc.) and organic concentration listed in two different measurement units. The Leachate table summarizes data from four regulatory batch tests – TCLP, SPLP, EPTox, and ASTM D-3987.

7.2. Developing Data Relationships

Choosing a relational database model over a network or hierarchical model ensures that any two tables interact according to four general relationships: one-to-one, one-to-many, many-to-many, or no relation. This step is crucial because it directly affects the data that can be accessed and viewed by the user. In addition, relationships among data that exist in real life must be carried over into the database to ensure practicality. Proper relationships mitigate data redundancy and poor user access to data.

7.3. Table Relationships

A one-to-many relationship exists between the Material and Process tables and between the Application and Process tables. The first signifies that each material can be processed in one or more ways before it is used as an engineering material. For example, scrap tires can be shredded to a particular size before compaction or the process can involve a series of shredding, steel belt removal through magnetic separation, and grinding to meet crumb rubber specifications. However, each process has one and only one material associated with it. As another example, recycled plastic, an element from the Materials table, can be processed into composite recycled plastic piles/lumber or it can be cut into small strips before it is incorporated into geotechnical systems. The difficulty is in developing the processing mechanisms so that they are specific enough to avoid overlap with other materials and yet general enough to ensure practicality. This is more of an issue with the process description field that is included in memo format. Concerning applications, the one-to-many relationship means that each of the eight applications (i.e. embankment/fill, asphalt pavement, flowable fill etc.) can be associated with more than one process. To employ a material as an asphalt modifier, it may be reclaimed, crushed, and screened or it may be mechanically combined into pellet form. Each process is associated with only one application. So it is that for the purposes of the database, each process is actually a unique combination of a material and an application, and the process table links the other two while establishing the many-to-many relationship between them. Each of the materials can be used in one or several applications and each application can be fulfilled by one or more materials.

The Process table is paramount. Besides linking the aforementioned tables, it also has a many-to-many relationship with the Performance or case study table. Each process, or unique material/application combination is documented by one or several case studies, and each case study may contain information relating to several processes. For example, a particular study may document the use of roof shingles and bottom ash in stabilized base applications. Roof shingles and bottom ash in embankments may also be at least part of the research of a different study. The linking table between Process and Performance (case study) is the aptly named Case/Process table; it contains the engineering and environmental parameters required to completely characterize the material. This table contains a vast amount of data. For example, a single record in this table might contain all the engineering data documented by a single study on kiln dust used as road base.

The final four tables, Chemical Composition, Metal Concentration, Organic Concentration, and Leachate are the environmental properties tables. They are connected to the rest of the database through a one-to-many relationship with the Case/Process table. Again, for a single material envisioned for single application, documented in a single case study, there exist several chemical compounds with corresponding weight percentages. This relationship carries through to the presence of several trace metals, several organic compounds, and several leachate test results – all for a single case/process combination. Figure 7-2 has been reproduced from Chapter 2, and it shows the database schema. Each table name is placed at the top in bold and each primary key is underlined. The lines delineate relationships among the tables with the '1' and '∞' representing the 'one' and 'many' relationships, respectively.

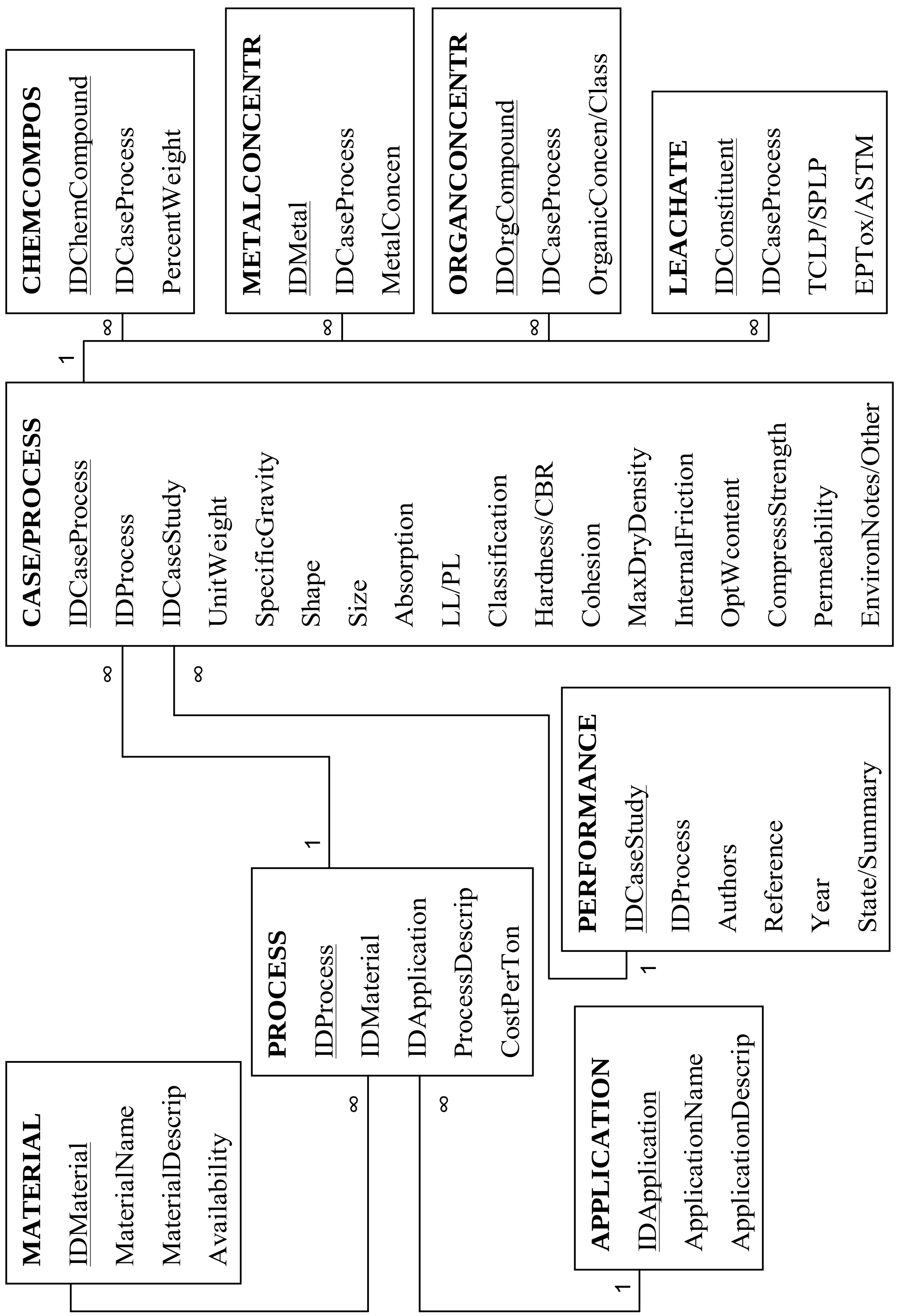

Figure 7-2: Database Schema

7.4. Content Overview

A more detailed examination of table headings and their corresponding fields is useful to understand how and where the data is inputted. Only the primary tables and those linking tables that contain important parameters are included in this discussion.

7.4.1. Material Table

Thorough review of the literature revealed 24 recycled materials suitable for this table. Although not encompassing every recycled material currently studied, these 24 provide a satisfactory, representative sample about which there is sufficient research. The materials belong to one of three categories based on their origin. Earlier, we identified these categories as domestic waste materials, industrial waste materials, and mineral waste materials.

7.4.2. Applications Table

This table displays eight applications – how the materials functions as part of a highway or geotechnical system. The applications are as follows: embankment/fill, flowable fill, concrete additive, asphalt pavement, base/subbase, stabilized base, soil reinforcement/stability, and other. Typically, embankment/fill applications involve raising a roadway with compacted material, providing a bridge approach, or similar activities. Select fill or other soil is usually used but can be mixed with or completely supplanted by aggregate-like recycled materials. Flowable fill, a self-cementing slurry, is generally used as excess fill in hard to reach areas such as near utilities and pipes. Recycled materials can be used in place of its components – either as aggregate or cementitious material. As concrete additives, recycled materials function as mineral admixtures that improve the strength, workability, and resistance to sulfates of the concrete. These materials are also used as substitute aggregate and/or mineral filler in asphalt pavement applications.

In base and subbase applications, recycled materials take the place of aggregate materials and cementing materials, and they function as a load transfer mechanism between overlying pavement and the soil underneath. Used in stabilized base, recycled materials take the place of aggregates if the latter is unavailable and may improve the self-cementing properties of the stabilized base. Soil reinforcement/stability is really two sub-applications. The first involves mixing a marginal soil with doses of a recycled material that improves the mechanical properties of the soil. The second refers to stabilizing slopes with discrete elements such as recycled plastic piles. The "other" category exists for aesthetic applications, very specialized applications, or those that do not involve transportation or geotechnical criteria.

7.4.3. Process Table

In addition to the aforementioned primary keys and linking fields, the process table is also composed of a description for each of the over 50 material/application combinations. Although each process is unique, many of the same actions are performed on the materials. These include shredding, screening, reclaiming, crushing, dewatering, stockpiling, and removing contaminant debris. Besides modifying them chemically, the recycled materials are often blended with other aggregate or fill to ensure uniformity or to meet gradation requirements. To process roof shingles that are to be used in asphalt pavement for example, debris must first be removed. Then the material is shredded, screened, stockpiled, and blended with other aggregate. Finally, it is moistened with water and added to the asphalt mixture. Concerning the database, the process description field is set to memo data type. This data type occupies more space than text but is essential in this case. A more detailed discussion of processes can be found in Chapter 4.

7.4.4. Performance Table

This table provides the compendium of relevant lab and field case studies. It is connected to the rest of the database through the process table. The fields are: Authors, Reference, Year, State, and SummaryMemo. For example, a lab case study from the Geotechnical Testing Journal by Yang et al. (2002) analyzes the mechanical properties of scrap tires. Specifically, the unit weight, size, shape, cohesion, and friction angle of the material are documented. The reference information is inputted into the Performance table, and the engineering parameters are added to the table that lists properties. Therefore, the database user may choose a process or a case study or an engineering property, and is immediately granted access to the other two pieces of information that correspond to that choice. The result is an interactive compendium of data that enables the users to start with one table of data either because they choose to or because that is the only data to which they have access, and then move through the corresponding records in the other tables.

7.4.5. Other Tables

A linking table joins the Process table with the Performance table. It is necessary to model the many-to-many relationship that exists. The Case/Process table has the following fields: unit weight, specific gravity, shape, size, absorption, liquid limit, plastic limit, classification, hardness, CBR, cohesion, maximum dry density, internal friction angle, optimum water content, compressive strength, other properties, and general environmental notes. Environmental tables incorporate the major constituents that may have a detrimental impact on the environment. Obviously, very few case studies depict all or even most of the above parameters. This fact does not detract from the usefulness of the database.

Environmental parameters such as presence of trace metals, existence and composition of organics, leachate properties, and general environmental notes are also contained in tables that attach to the Case/Process table. Again, each case study may provide very little information concerning environmental properties or it may be more comprehensive in nature.

7.5. Using the Database

The completed tables are the compendium of recycled materials data. However, it is the interaction and manipulation of the data that gives the database its practicality. In the database management system, this is accomplished through the creation of forms, queries, and reports.

7.5.1. Forms

Forms serve as filters so users can see data in an easily accessible format (Whitehorn and Marklyn, 2003). Unless the users are familiar with the database design and existing relationships between data sets, they cannot update it with new information. Typically, forms are the only method through which the user interacts with the data. For the recycled materials database, two sets of forms are created for each of the nine tables. As a result, the users can easily view existing information or they may add new recycled materials, new applications, new processes, new case studies, or new parameters to the database as the research is completed.

The forms for viewing existing data are created with functionality in mind. The user is not allowed to add to or edit information to the database in any of the nine forms through the 'view existing data' form set. This is accomplished through locking the forms to which the data tables are connected. It is a safeguard against misuse and/or data contamination that may result from making the database available. The authors of this report and the database designer can only be held responsible for the design of the database. The 'view existing data' form set is formatted with a yellow and green background so that the users develop an awareness of where they are at in the database. An example form from the 'view existing data' form set is shown in Figure 7-3.

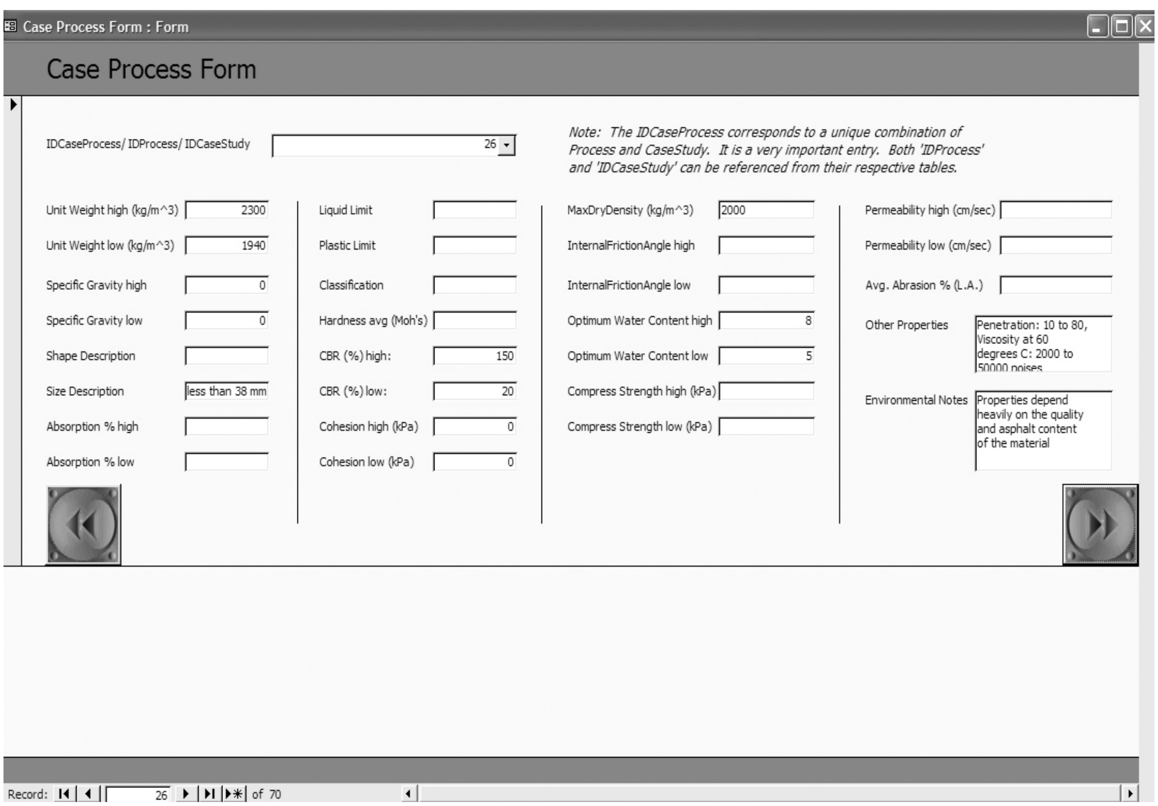

Figure 7-3: Case Process Form ('View Existing Data')

The forms for adding new data are blank and are formatted to provide an automatic increment in primary key autonumbers each time a new record is added. One drawback is that as the users move from form to form entering data, they must click the "save" button to update the information they have already inputted into the corresponding data tables. Failure to do so negates any efforts at data entry. The 'add new data' forms are equipped with a burgundy and gray background so that the users are aware they should be adding new data. A form of this type is reproduced in Figure 7-4. A new recycled materials database, which is currently being developed at the University of South Florida separately from this project, overcomes these limitations.

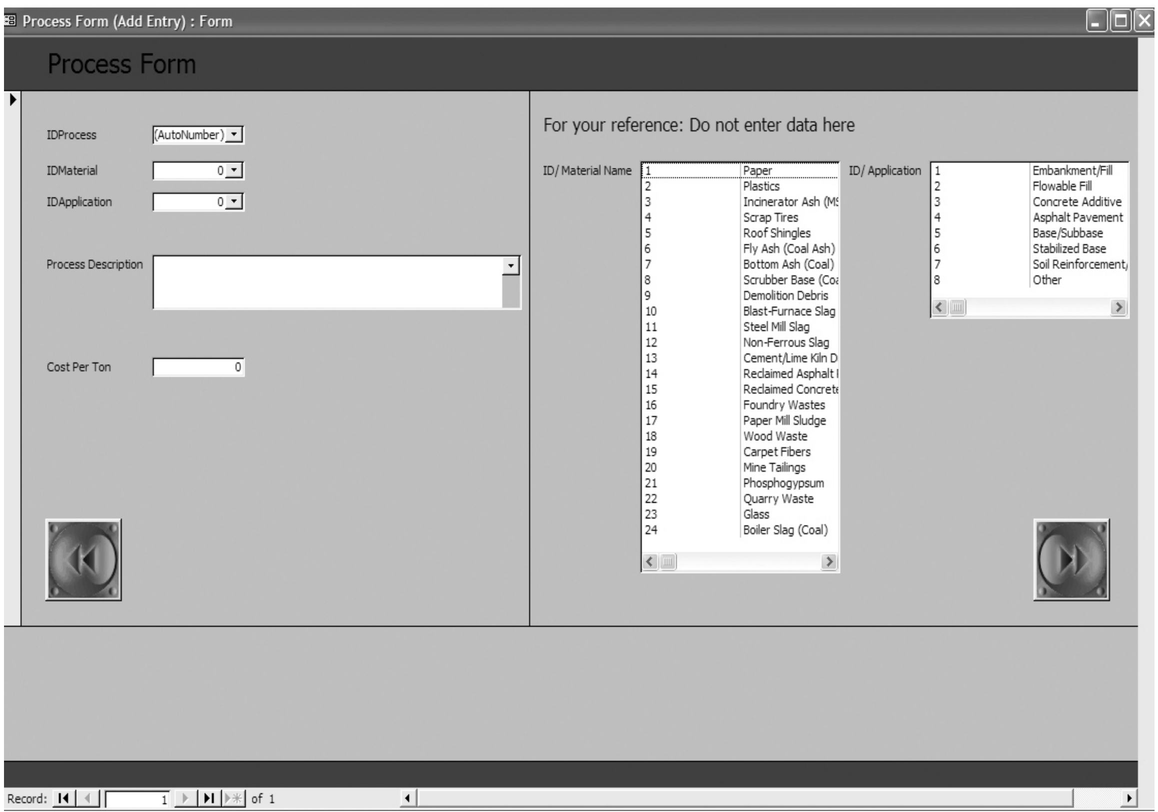

Figure 7-4: Process Form ('Add New Data')

Although not included in the database framework, forms may also be created from queries. A user can simply attach a form to a query. Each time the user types in a word, phrase, number, or other data in the appropriate field, the query finds the relevant information and summarizes it for the user. Connecting a form to a query merely improves the visual aspects of the user interaction with queries. It is equally functional to allow the user to create a custom query with the help wizard or design his own. There are too many features provided by the database management system to design for each and every one.

7.5.2. Queries

One of the purposes of queries is to find specific portions of data. They are questions that extract a subset of data displayed in the form of a summary table. However, they also have the potential to perform mathematical manipulation of existing data. General queries are created for some of the data subsets that attract interest. These include queries for each of the eight applications, queries for each of the twenty-four materials, queries for each of the over 50 processes, and queries for some of the more prolific authors of recycled materials case studies. In addition to the standard queries, the user has the option of creating custom queries. If for example, the user is only interested in a material or process that exhibits a certain compressive strength, a query may be used to display all the materials and processes that meet that criterion. The user may also create a custom query to avoid any process or case study that corresponds to a particularly troublesome chemical compound. Queries can be set up to search for incredibly detailed information or for more general lists. In addition to queries that simply select data drawn from multiple tables, there are four more types. Table 7-1 lists all query types.

Table 7-1: Types of Queries (Whitehorn and Marklyn, 2003)

Query Type	Usage
Select	Select fields/records from table according to specified criteria
Parameter	Displays prompt boxes to supply query criteria
Range	Selects fields/records which contain a range of values
Group By/Crosstab	Displays summarized values (sums, averages) in a grid
Action	Performs actions to change records or create new tables

In the given database, queries are created constantly to generate reports, view gaps in the data, and summarize information for presentations. An example query is created here for reference. The query assumes interest in all possible applications for coal fly ash. In addition, the assumption is made that the user wants to know the range of values for specific gravity as well as the high end values for both internal friction angle and permeability. Figure 7-5 shows the design view of the custom 'select' query.

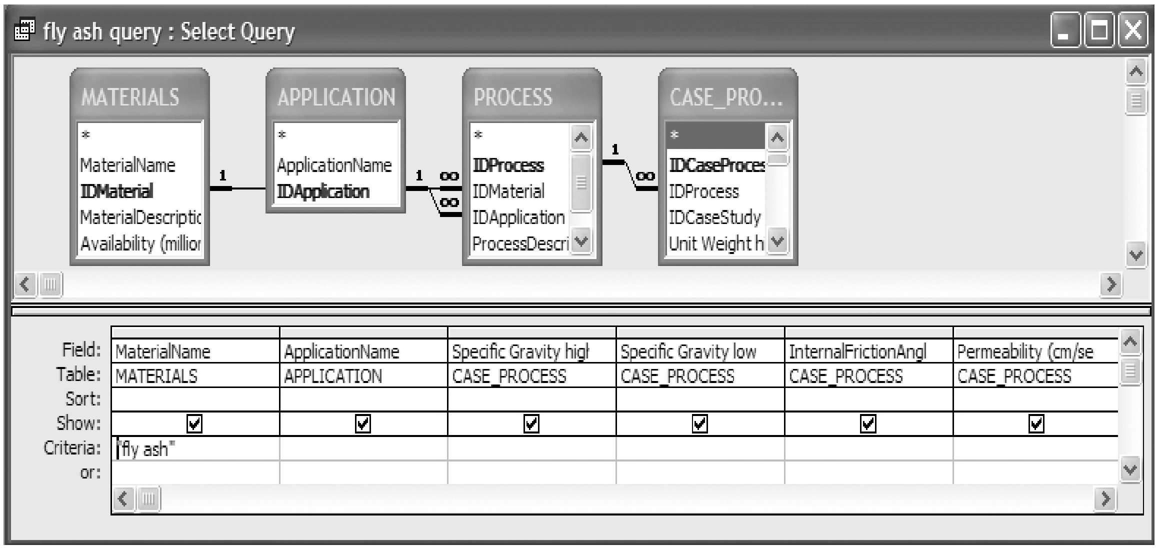

Figure 7-5: Fly Ash Query Design

The output is generated in the form of a table, which combines the fields of interest from the Material, Application, and Case/Process tables. The output can be used to generate a report or form. Figure 7-6 shows the output from the fly ash 'select' query.

fly ash query : Select Query

Materiall	ApplicationName	Specific Gravity	Specific Gravity	InternalFric	Permeability
Fly Ash	Embankment/Fill	2.62	2	45	0.001
Fly Ash	Embankment/Fill	3	2.1	42	0.0001
Fly Ash	Flowable Fill	2.62	2	45	0.001
Fly Ash	Flowable Fill	3	2.1	30	
Fly Ash	Concrete Additive	2.62	2	45	0.001
Fly Ash	Concrete Additive	3	2.1		
Fly Ash	Asphalt Pavement	2.62	2	45	0.001
Fly Ash	Asphalt Pavement	3	1.7		
Fly Ash	Stabilized Base	2.62	2	45	0.001
Fly Ash	Stabilized Base	3	2.1		
Fly Ash	Base/Subbase	2.7	2.65		

Record: 12 of 12

Figure 7-6: Fly Ash Query Output

7.5.3. Reports

A report is simply a collection of summarized information that is acceptable for printing. Unlike forms, their purpose is not user interaction. Instead, reports prepare data for printing and presentation. To function properly, the database does not require their creation. However, the user can easily create custom forms from existing or custom queries to use in presentations or in hard copies of documents. One such report is created below. Figure 7-7 shows a portion of the report created from the 'select' custom query for fly ash. This time, the only information of interest is the material, fly ash, its applications, and range of specific gravity.

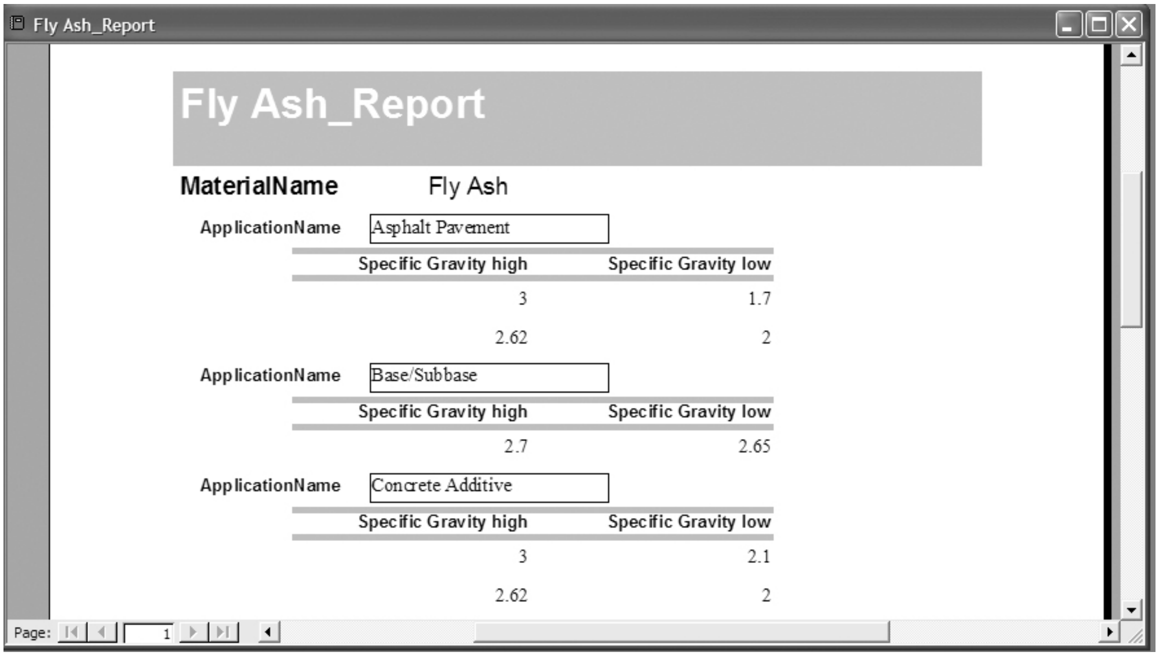

Figure 7-7: Fly Ash Custom Report

7.6. Interface

The interface is setup to provide an aesthetically pleasing backdrop wherein the user can view existing data or add new data. The importance here is to provide an easily navigable interface so that the user does not get lost. This is accomplished by linking components of the interface to produce a seamless whole.

7.6.1. Navigating Existing Data Forms

When the user opens the database, a switchboard opens that allows the user to choose between two options – 'View Existing Data' or 'Add New Data.' Choosing the first option takes the user directly to the first form in the 'view existing data' set – the Material form. The Material form window actually opens on top of the switchboard, concealing it from view. The default view of the first record for the material, Paper, is showing. The user can scroll through all the records in the Material table, viewing each field in from the 24 records that correspond to the 24 materials. The user may then move to the next form in the sequence, the Application form, by clicking on the next arrow and continue examining records or he may close the Material form by clicking on the back arrow. Each subsequent form window opens on top of the preceding form but may always be closed by clicking on the "Back" button. The final form in the sequence, the Leachate form, is equipped with an additional option of returning to the home or switchboard. The entire sequence is as follows: Material, Application, Process, Performance, Case/Process, Chemical Composition, Metal Concentration, Organic Concentration, and Leachate.

7.6.2. Inserting New Data Forms

If the user instead chooses the second option, 'Add New Data,' a second switchboard opens revealing four additional choices. The user may 'Add New Material,' 'Add New Application,' 'Add New Process,' or 'Add New Case Study.' Each choice opens a different form that is separate from the 'view existing data' form set. These forms have burgundy and gray backgrounds, and their fields are initially blank. Choosing the first option will send the user to the Material (Add Entry) form into which the user can input a new material by typing it into the appropriate field (MaterialName). Here the primary key, IDMaterial, automatically increments to the next number – in this case 25, and the rest of the fields within the form can be filled in by the user. A list box containing all existing materials is included for user reference. If for some reason the user enters a material that already exists, it will not be possible to save the changes made to the form. This is because the property 'index: Yes (no duplicates)' in the field corresponding to material name has been selected. This is true for all fields where duplication would create confusion or otherwise slow the flow of data.

After entering the information required, the entry is saved by clicking on the 'save' button and the user navigates to the next form in the series, the Application (Add Entry) form where a similar process is followed. Upon continuing to the Process (Add Entry) form, a new process may be added. However, since a process is a unique material/application combination, a new process may be the result of adding a new material, adding a new application, adding both, or simply creating a new combination from an existing material and an existing process. To ensure consistency, the Process form is equipped with combo boxes, or pull-down boxes from which the user may select an existing IDMaterial and an existing IDApplication. The most recent of these values also shows up as the last entry in the choices within the combo box. When the user selects these values, a new IDProcess number automatically increments to create a new process.

The second switchboard has four options to help the user control data input. For example, the user may need to add just a new material, or just a new application. Perhaps the user may choose instead to create a new process from an existing material and an existing application. In this case, choosing the option at the second switchboard to 'Add New Process,' allows skipping the first two forms. The same is true for the Performance (Add Entry) form, which permits a user to enter new reference information from a recent case study. In choosing any of the four options, the user will eventually work his way through the entire sequence of forms – saving each new record throughout. A partial flow diagram delineating user navigation between forms is shown in Figure 7-8.

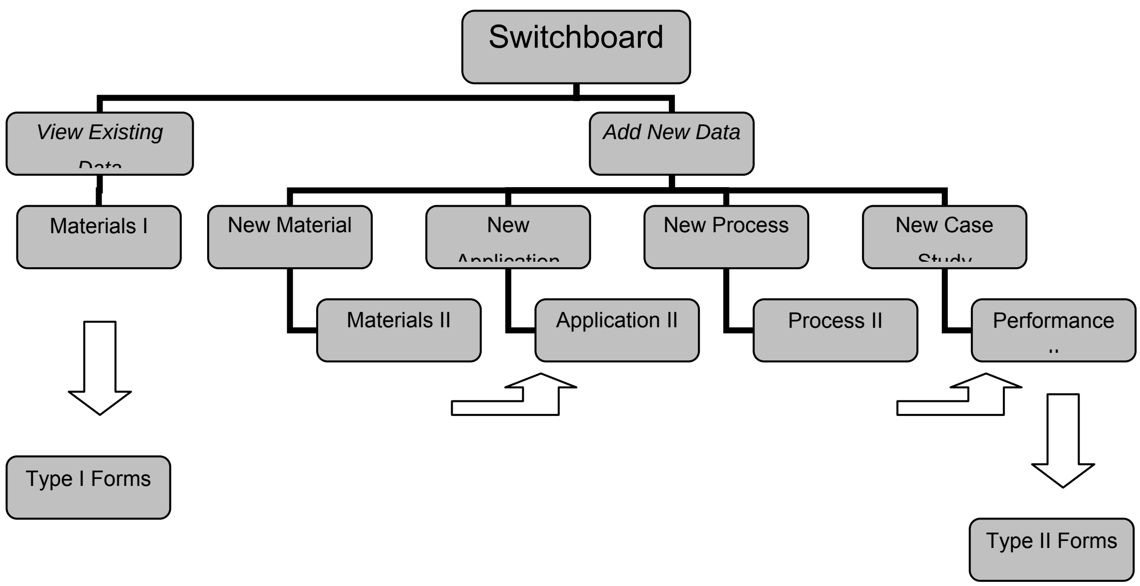

Figure 7-8: Interface Flow Diagram

7.7. Modification

It is impossible to design the database to cater to the needs of every engineering or research professional. The database is only a framework, albeit a robust one, which can be added to, improved, or even revamped. A database professional could certainly take advantage of features such as macros, scripts, or even create an improved interface through original code. On a more basic level, a designer might choose to add additional tables that organize pertinent recycled material data not included here. In addition, fields can be added within existing tables or removed at the discretion of the designer. It is envisioned that the relational database is the beginning – a first step in bridging the gap between academic research and engineering practice in recycled materials.

8. Conclusions and Recommendations

8.1. Conclusions

The use of recycled material in the stabilization of marginal soils must not be conceived as an avenue for the supplier to dispose of their waste. To the contrary, the use of such materials in roadway and highway construction must provide a clear advantage in terms of improvement of the engineering properties of the foundation, subbase, base, slopes, or embankment materials.

The data presented above shows that the environmental properties of most of these materials are within the acceptable limits. However, it can also be seen that there are times where many of the materials have environmental properties that are not acceptable by the current regulatory levels. In addition, the lack of adequate quantities of some of the materials creates a major obstacle to their continuous use over long periods of time, and thus raises a question of feasibility. This lack of uniformity among the characteristics of the various materials shows the importance of detailed engineering and environmental testing, as well as the importance of consistently satisfying the current regulatory limits for various environmental properties.

8.2. Recommendations

This section is meant not to present conclusions on the use of precise materials in specified applications. Rather, this information should be drawn by the reader and the user of the database. The focus is placed on more qualitative recommendations, suggestions for further recycled material research, and additional database feature propositions.

8.2.1. <u>General Recommendations</u>

From reading the literature and speaking with engineering professionals, it is apparent that a quality control mechanism must be in place if the goal of recycled materials implementation is to be achieved. Perhaps the most expeditious method to achieve it is through source control. By ensuring that a material comes from the same source and is processed in a consistent way, many of the variables associated with engineering performance and environmental impact can be at least partially controlled. The wide range of engineering parameters especially for unit weight, LBR, internal friction angle, permeability, and compressive strength emphasize the need to test materials at the local level from a controlled source using specified sampling procedures. Once consistency can be established, and more importantly assured at the local level, the use of recycled materials will be greatly facilitated. High up-front costs associated with quality control through testing should lead to lower costs in the future. In addition, it is advisable to involve national and state environmental organizations such as EPA and DEP at every stage. Besides agency control of recycled materials, another option is to place the burden of quality control squarely on the sellers – recycling firms and materials generators. The responsibility of presorting, processing, testing, and possibility transport – all to achieve a quality product, will be handled by those profiting from the sale of the material.

8.2.2. Database Recommendations

The addition of several components has been suggested and their incorporation into the database may be beneficial to both academics and engineers. The first is to bring some element of local availability and cost into the database. This would require investigating local market sources of each recycled material. In this way, a user would have access to a variety of pertinent information. For example, three different plants might sell a particular recycled material for a specified price with a given list of engineering properties and long-term environmental impact data. Access to this kind of information would be invaluable not only to design engineers and contractors, but also to state agencies and environmental organizations. A general database recommendation is to develop parameter or select queries to be connected to the interface through their own form set. Finally, the debugging process must continue, the interface can be improved, and wider access to the database can be achieved by making the database available online.

8.2.3. Acceptance and Permitting Guidelines

Beneficial Use Demonstrations (BUDs) are required by FDEP before the use of some of the materials. They stipulate that the applicant (FDOT or contractor) submit extensive data and documentation to support a particular beneficial use of a waste material or industrial by-product. Specific guidance documents for BUDs have been issued for incinerator ash and recovered screening materials (RSM) from C&D waste.

As a result of FDEP and EPA regulations, any material that does not conform to published environmental rules and regulations in terms of classification as a non-hazardous waste must be discarded a priori. In addition, any material that does not provide a direct benefit in terms of improving the engineering properties of the marginal soil must also be rejected from consideration. The flow charts shown in Fig. 8-1 and 8-2 was prepared to facilitate the decision making process regarding whether or not a particular material can be approved for use.

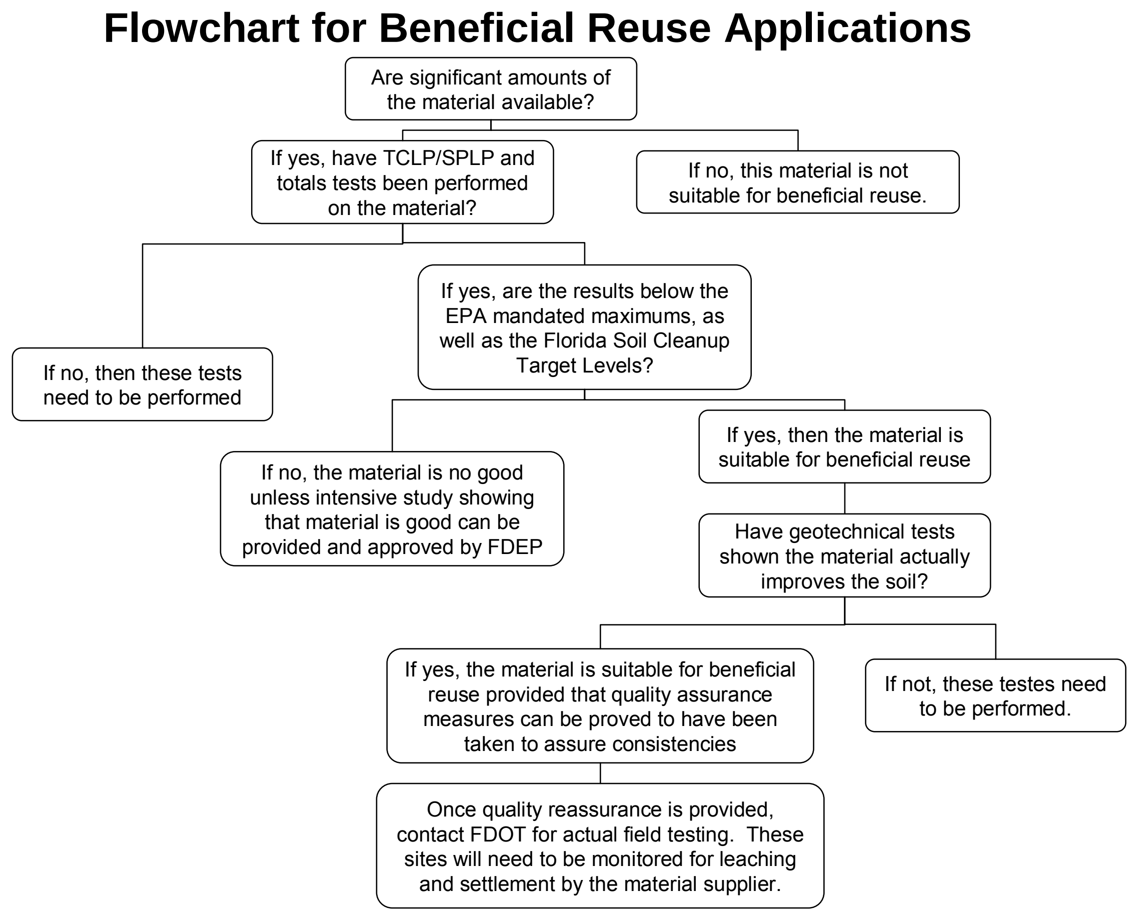

Figure 8-1: Flowchart to assist FDOT in beneficial use applications for new materials

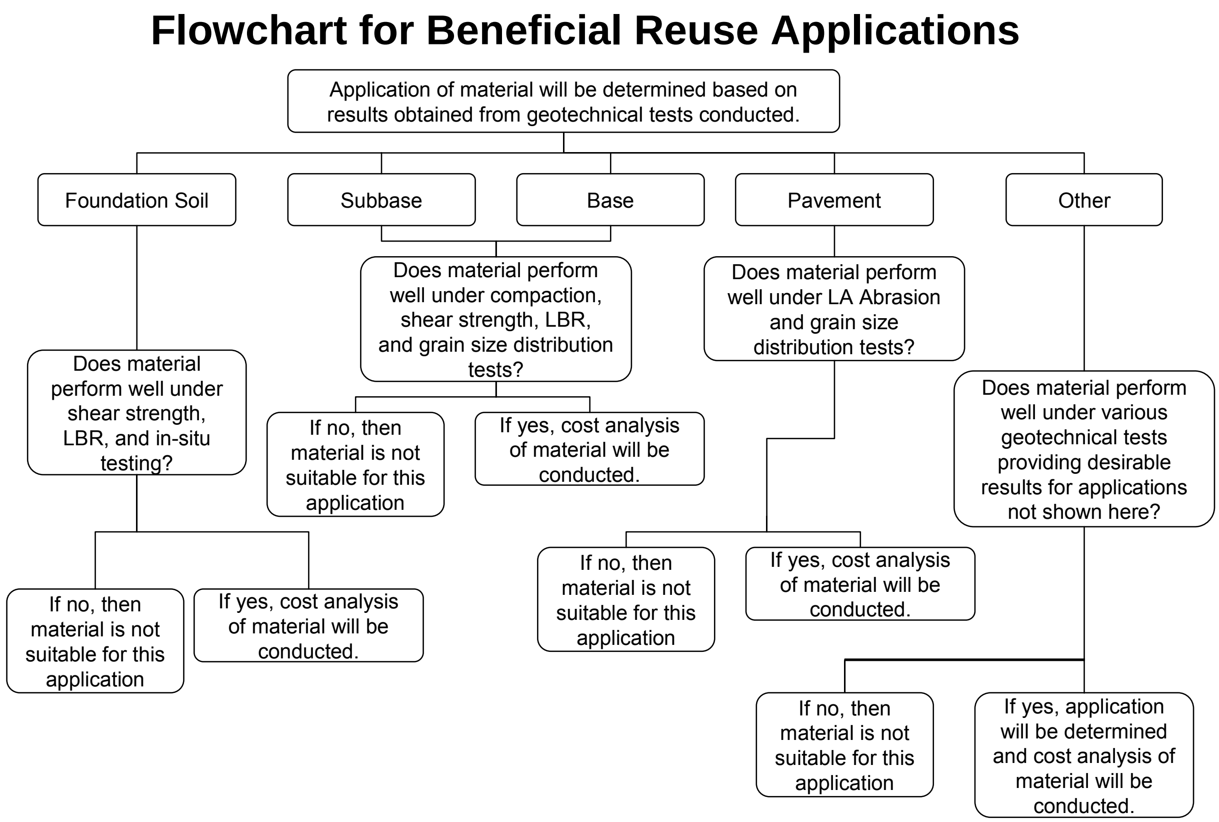

Figure 8-2: Flowchart to assist FDOT in determining the use of recycled materials based on application.

At all steps, suppliers and providers of recycled materials must be informed from the early stages that the use of recycled materials in highway and roadway applications, particularly for improving the properties of marginal soils, does not provide and should not be approached as an avenue to dispose of the material. Instead, the proposed material and process must provide mechanical improvements to the soil, economic advantages to FDOT, and must comply with environmental regulations.

It should also be noted that samples used for testing and demonstrations are generally selected from a few batches and may therefore not be representative of the material as a whole. Care should be taken by FDOT personnel as different recycling companies and/or agents utilize different recycling and post-processing methods. Therefore, results for the tests on a sample obtained from a different supplier might be very different from the results presented in this report or provided by a supplier due to variations in methods collection and processing. This also applies when referring to studies conducted by other states to obtain permission for beneficial reuse in Florida. Other states often have different methods and regulatory requirements that yield different results, and the case studies must be unique to the material of concern at the location it is being recycled and marketed.

In addition, it is very important to point out that the environmental tests are only meant to simulate the natural conditions to which the material will be subjected, and the results may not be exact representation of what might occur in actual field conditions. Hence, the appropriate permitting agency should be contacted with the results on-hand, and permission for actual site testing should be requested. It is essential that actual site testing be performed to monitor the behavior of the material in its desired state. Monitoring wells should be setup to measure the in-situ leaching characteristics of the material on site. Recommendations for ground water monitoring and land treatment monitoring can be found in Chapters 11 and 12 of EPA SW-846.

Based on the data collected in the present study, Table 8-1 was developed as a comprehensive reference to summarize the key points in relation to each of the materials. This table could serve as a rudimentary blueprint for the current study, and is envisioned to be utilized as a quick reference for FDOT personnel.

Table 8-1. Summary table for characteristics and reuse outlook of recycled materials (3 pages)

Material	Annual Quantity available[1]	Engineering Properties	Environmental Properties	FDEP Status	Potential Applications	Concerns	The Bottom Line
Paper	Abundant 4.5 million tons	Unfavorable	Safe	Mostly approved[2]	Temporary reinforcement		Not recommended
Plastics	Abundant >1 million tons	Good, needs further study	Mostly safe	Widely approved[2] with few exceptions	Reinforcement of slopes, embankments		Promising material, especially plastic lumber
Scrap Tires	Reasonable 50,000 tons	Good	Safe if processed properly	Approved[2], regulated by Rule 62-711, F.A.C.	Lighweight fill, filters, drains, crumb rubber for asphalt	Exothermic reaction	Currently used, widely promising
Glass	Limited <1 million tons	Very good	Borderline, unless properly processed	Questions regarding lead contamination	Aggregate		Limited quantity does not warrant use
Carpet Waste	Limited 300,000 tons	Poor	Safe	Undefined, but approval likely	Erosion control, concrete reinforcement		Not recommended due to poor properties
Incinerator Ash	Reasonable 1.5 million tons	Excellent	Borderline	BUD guidance available	Base, subbase, embankments		Highly promising when mixed with soil. BUD must be conducted
Fly Ash	Scarce due to current reuse	Excellent	Unfavorable	Regulated, approved[2] for specific applications	Currently used as a concrete additive	Corrosivity	Current re-use levels at 100%
Bottom Ash	Scarce due to current reuse	Excellent	Fair	Regulated, approved[2] for specific applications	Currently used in concrete and road base	Corrosovity, low pH	Current re-use levels approaching 100%
Boiler Slag	Scarce	Excellent	Fair	Regulated, approved[2] for specific applications	Currently used in concrete and road base	Corrosovity, low pH	Current re-use levels approaching 100%
Scrubber Base	Scarce due to current reuse	Very good	Fair	Regulated, approved[2] for specific applications	Currently used in drywall and concrete		Current re-use levels approaching 100%
Blast Furnace Slag	Scarce	Very good	Questionable	Undefined, likely to be approved	Base material, embankments	Variability in G_s is high	Quantity too small to warrant consideration
Foundry Sand	Scarce	Good	Fair	Undefined, likely to be problematic	Base material, embankments		Quantity too small to warrant consideration
Steel Mill Slag	Scarce due to current reuse	Very good	Acceptable	Approved[2]	Reused as granular base or aggregate	Expansive if not properly cured	Current re-use levels at 100%

Table 8-1. Summary table for characteristics and reuse outlook of recycled materials (3 pages)

Material	**Annual Quantity available**[1]	**Engineering Properties**	**Environmental Properties**	**FDEP Status**	**Potential Applications**	**Concerns**	**The Bottom Line**
Non Ferrous Slag	Scarce	Varies, but mostly good	Questionable	Unknown, likely to be problematic	Granular base, aggregate	Variability in properties is high	Quantity too small to warrant consideration
Kiln Dust	Scarce due to current recycling	Poor	Poor	Unknown, but irrelevant due to 100% recycling	Cement additive		Currently fully recycled
C&D Waste	Abundant 3.3 million tons	Good to poor	Questionable	Regulated by Section 403.707(12)g, F.S. BUD guidance available	None, unless sorted and separated into components		Highly variable materials. Must be separated into components
RAP	Scarce due to current recycling	Very good	Acceptable	Approved[2]	Asphalt, base material		Currently fully recycled
RCA	Scarce due to current recycling	Very good	Acceptable	Approved[2]	Concrete, aggregate, rigid pavement		Currently approaching 100% recycled levels
Roof Shingles	Reasonable 1 million tons	Poor to fair	Questionable, due to asbestos and trace metals	Unknown, likely to be approved. Must comply with relevant C&D waste regulations	Asphalt pavement	Variability in properties is high. Material creeps in the long term	Environmental concerns and quality control are main obstacles
Paper Mill Sludge	Small 200,000 tons	Poor	Unfavorable	Unknown, likely to be problematic	Aggregate binder	Difficult to condition for construction	Environmental properties and poor engineering performance are main obstacles
Wood Waste	Scarce <200,000 tons	Poor	Fair to good	Varies, mostly approved[2]	Temporary reinforcement, temporary fill		Mostly reused as combustion fuel and compost
Quarry Waste	Scarce due to current re-use	Very good	Varies, but mostly good	Mostly approved[2]	Base, subbase, embankments		Mostly reused in industrial applications
Mine Tailings	Scarce	Poor to good	Varies, but mostly unfavorable	Varies, but more likely to be problematic	Aggregate binder, subbase, base		Not recommended due to environmental hazards
Phospho-gypsum	Abundant	Excellent	Unfavorable (radioactivity and trace metals)	Regulated by Rule 62-6731, F.A.C.	Base and subbase, stabilization of sand and clay	Highly sensitive to water content	Currently “banned” by environmental regulations

[1] This table includes only estimates of the **excess** quantities of material available for additional re-use. It does not include any quantities that are committed or are consistently being recycled or re-used in beneficial applications.

[2] The term "approved" does not imply a blanket approval for usage of the material without securing the appropriate FDEP permits, as well as permits from county and local regulatory bodies.

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APPENDIX I - Material Suppliers and Contacts in Florida

Paper

American Forest and Paper Association

http://www.afandpa.org

Cathy Norris Ext. 5162

Paper Loop

http://www.paperloop.com

Southland Waste Systems

8619 Western Way, Jacksonville, FL 32256

(904) 731-1232

City of Tampa Solid Waste Department

4010 West Spruce Street - Tampa, Florida 33607

Phone: (813) 348-1111 Fax: (813) 348-1156

David McCary, Director

Phone: (813) 348-1148

Hillsborough County Solid Waste Management

Daryl Smith, Director

24th Floor, County Center

Telephone: 272-5680

Fax: 276-2960

Plastics

US Plastic Lumber Company

Ocala, FL

(888)733-2546 (Steven Schultz)

Commercial Plastics Recycling
1212 North 39th St.
Tampa, FL 33605
Contact: Ben Benvenuti <benb@cprinc.net>
813-248-4212
813-248-5634 (fax)
http://www.cprinc.net

Noble Recycling Inc.
1375 Gateway Blvd
Boynton Beach, FL 33426
Phone: (561) 536-0595
Fax: 561/423-2257
Email: sales@noblerecycling.com
http://www.noblerecycling.com

American Recycled Plastic, Inc.
Palm Bay, FL 32905
(866) 674-1525
Plastic Nation Inc
20283 State Rd 7 #104
Boca Raton, FL 33498
Phone: 561-482-9300 <mark@plasticnation.com>
Fax: 561-482-9369

Roof Shingles

Rupert Bodden
(813) 841-5527
Jay Moore
(813) 785-9246

Florida Shingle Recycling
5916 21st St. East
Bradenton, FL 34203
(941) 756-6201

<u>Fly Ash, Bottom Ash, Scrubber Base, and Boiler Slag</u>

Ash Services Holdings
(561) 799-9688
(561) 625-6018
7100-39 Fairway Drive PMB 219
Palm Beach Gardens, FL 33418

Florida Electric Power Coordinating Group, Inc.
(813) 289-5644
(813) 289-5646
1408 N. Westshore Blvd., Ste. 1002
Tampa, FL 33607-

ISG Resources, Inc.
(352) 365-6166
105634 East Harbor
Fruitland Park, FL 34731

Jacksonville Electric Association (JEA)
(904) 665-8911
11201 New Berlin Road
Jacksonville, FL 32226

Lafarge NA
(941) 722-3480
304 Nation Street
Palmetto, FL 34221

Lakeland Electric
(863) 834-6583
3030 E. Lake Parker Drive
Lakeland, FL 338059513

MRT - A CEMEX Company
(813) 671-2266
6725 78th Street
Riverview, FL 33569

Progress Energy
(352) 563-4484
P.O Box 15208
St Petersburg, FL 33733

Seminole Electric Cooperative, Inc.
(813) 739-1213
(813) 264-7906
P.O. Box 272000
Tampa, FL 33688-2000

Synthetic Materials - SYNMAT
(727) 367-0400
(727) 367-0402
P.O. Box 67245 244 Old Highway 149
St. Pete Beach, FL 33736-

Tampa Electric Company
(813) 641-5054
(813) 641-5066
P.O Box 111
Tampa, FL 33602

C&D Waste

Econowaste, Inc.
P.O. Box 49250
Jacksonville, FL 32240-9250
Phone: 904-642-5475
Fax: 904-645-9047

Blast-Furnace Slag

Florida Rock
John D. Milton, Jr., Executive Vice President, Treasurer and Chief Financial Officer
155 East 21st Street
Jacksonville, Florida 32206
(904) 355-1781

Titan America
11201 New Berlin Rd.
Jacksonville, FL 33226
1-888-4PROASH

Tarmac (part of Titan America)
339 Thorpe Road
Orlando, FL 32824
(407) 240-9824

Steel Mill and Non-Ferrous Slag

Florida Steel Corporation
4006 Paul Buchman Hwy, Plant City, FL 33565
Phone: (813) 752-7550

Ameristeel
217 Yellow Water Road, Jacksonville, FL 32234
(904) 266-2454

Cement/Lime Kiln Dust

Florida Concrete Producers Association
http://www.fcpa.org

Southdown, Inc
1021 SE US Highway 19
Crystal River, FL 34429
(352) 867-5794

Florida Mining and Materials Cement Division
6659 Highway Avenue
Jacksonville, FL 32254
(904) 781-8785

Reclaimed Asphalt Pavement and Reclaimed Concrete Pavement

FDOT
State Materials Office
Gainesville, FL

Foundry Wastes

Maddox Foundry & Machine Works, Inc.
100 Mechanic Street
PO Drawer 7
Archer, FL 32618
(352) 495-2121

US Foundry & Manufacturing Corporation
4408 West Martin Luther King Jr. Drive
Tampa, FL 33614
(813) 876-3278

Paper Mill Sludge

Atlas Paper Mills
3475 Nw 60th St
Miami, FL 33142
Ph1: (305) 636-5740
Fax: (305) 696-0421
Ph2: (305) 835-8046

Marcal Paper Mills
Miami, FL 33157
(305) 253-5757

Monadnock Paper Mills Inc
9090 Little Gasparilla Island
Placida, FL 33946
(941) 698-0665

Wood Waste

See C&D Waste

Carpet Fibers

SWIX (Southern Waste Information Exchange)
Attn: Ray Moreau

Mine Tailings

du Pont de Nemours & Company, Inc.
Florida Plant
Post Office Box 753
Starke, Florida 32091
(904)964-1200

Iluka Resources, Inc.
1223 Warner Road
Green Cove Springs, Florida 32043
(904)284-9832

Phosphogypsum

Florida Institute of Phosphate Research (FIPR)
Bartow, FL
Dr. Brian Birky, FIPR's Public Health Research Director
(863) 534-7160 birky@mail.usf.edu
http://www.fipr.state.fl.us/index.html

<u>Quarry Waste</u>

Crystal River Quarries Inc
(352) 795-2409
7040 North Suncoast Boulevard
Crystal River, FL 34428

Southern Sand and Stone Inc
(239) 775-0720
9220 Collier Boulevard
Naples, FL 34114

Rinker Materials
Aggregate Division, Krome Quarry Scale House
(305) 388-7221
8800 Southwest 177th Avenue
Miami, FL 33196

<u>Glass</u>

City of Tampa, Solid Waste Department
4010 West Spruce Street - Tampa, Florida 33607
Phone: (813) 348-1111 Fax: (813) 348-1156
David McCary, Director
Phone: (813) 348-1148

Hillsborough County, Solid Waste Management
Daryl Smith, Director
24th Floor, County Center
Telephone: 272-5680
Fax: 276-2960

APPENDIX II - EPA Maximum Contaminant Levels (MCL) Limits

EPA National Primary Drinking Water Standards

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Acrylamide	TT[8]	Nervous system or blood problems;	Added to water during sewage/wastewater increased risk of cancer treatment	zero
OC	Alachlor	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops	zero
R	Alpha particles	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero
IOC	Antimony	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006
IOC	Arsenic	0.010 as of 1/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes	0
IOC	Asbestos (fibers >10 micrometers)	7 million fibers per Liter (MFL)	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 MFL
OC	Atrazine	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops	0.003
IOC	Barium	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2
OC	Benzene	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero
OC	Benzo(a)pyrene (PAHs)	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero
IOC	Beryllium	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries	0.004
R	Beta particles and photon emitters	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero
DBP	Bromate	0.010	Increased risk of cancer	Byproduct of drinking water disinfection	zero
IOC	Cadmium	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005
OC	Carbofuran	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa	0.04
OC	Carbon tetrachloride	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities	zero
D	Chloramines (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes	MRDLG=4[1]

LEGEND

D	Dinsinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

1

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Chlordane	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero
D	Chlorine (as Cl_2)	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes	MRDLG=4[1]
D	Chlorine dioxide (as ClO_2)	MRDL=0.8[1]	Anemia; infants & young children: nervous system effects	Water additive used to control microbes	MRDLG=0.8[1]
DBP	Chlorite	1.0	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection	0.8
OC	Chlorobenzene	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1
IOC	Chromium (total)	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1
IOC	Copper	TT[7]; Action Level = 1.3	Short term exposure: Gastrointestinal distress. Long term exposure: Liver or kidney damage. People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits	1.3
M	*Cryptosporidium*	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
IOC	Cyanide (as free cyanide)	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories	0.2
OC	2,4-D	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops	0.07
OC	Dalapon	0.2	Minor kidney changes	Runoff from herbicide used on rights of way	0.2
OC	1,2-Dibromo-3-chloropropane (DBCP)	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero
OC	o-Dichlorobenzene	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6
OC	p-Dichlorobenzene	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories	0.075
OC	1,2-Dichloroethane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	1,1-Dichloroethylene	0.007	Liver problems	Discharge from industrial chemical factories	0.007
OC	cis-1,2-Dichloroethylene	0.07	Liver problems	Discharge from industrial chemical factories	0.07
OC	trans-1,2-Dichloroethylene	0.1	Liver problems	Discharge from industrial chemical factories	0.1
OC	Dichloromethane	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories	zero
OC	1,2-Dichloropropane	0.005	Increased risk of cancer	Discharge from industrial chemical factories	zero
OC	Di(2-ethylhexyl) adipate	0.4	Weight loss, live problems, or possible reproductive difficulties	Discharge from chemical factories	0.4
OC	Di(2-ethylhexyl) phthalate	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories	zero
OC	Dinoseb	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables	0.007
OC	Dioxin (2,3,7,8-TCDD)	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories	zero
OC	Diquat	0.02	Cataracts	Runoff from herbicide use	0.02
OC	Endothall	0.1	Stomach and intestinal problems	Runoff from herbicide use	0.1

LEGEND

D	Dinsinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

2

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Endrin	0.002	Liver problems	Residue of banned insecticide	0.002
OC	Epichlorohydrin	TT8	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals	zero
OC	Ethylbenzene	0.7	Liver or kidneys problems	Discharge from petroleum refineries	0.7
OC	Ethylene dibromide	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries	zero
IOC	Fluoride	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories	4.0
M	*Giardia lamblia*	TT3	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC	Glyphosate	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use	0.7
DBP	Haloacetic acids (HAA5)	0.060	Increased risk of cancer	Byproduct of drinking water disinfection	n/a6
OC	Heptachlor	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide	zero
OC	Heptachlor epoxide	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor	zero
M	Heterotrophic plate count (HPC)	TT3	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment	n/a
OC	Hexachlorobenzene	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories	zero
OC	Hexachlorocyclopentadien e	0.05	Kidney or stomach problems	Discharge from chemical factories	0.05
IOC	Lead	TT7; Action Level = 0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits	zero
M	*Legionella*	TT3	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems	zero
OC	Lindane	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens	0.0002
IOC	Mercury (inorganic)	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands	0.002
OC	Methoxychlor	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock	0.04
IOC	Nitrate (measured as Nitrogen)	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	10
IOC	Nitrite (measured as Nitrogen)	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	1

LEGEND

D	Dinsinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Oxamyl (Vydate)	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes	0.2
OC	Pentachlorophenol	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories	zero
OC	Picloram	0.5	Liver problems	Herbicide runoff	0.5
OC	Polychlorinated biphenyls (PCBs)	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals	zero
R	Radium 226 and Radium 228 (combined)	5 pCi/L	Increased risk of cancer	Erosion of natural deposits	zero
IOC	Selenium	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines	0.05
OC	Simazine	0.004	Problems with blood	Herbicide runoff	0.004
OC	Styrene	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	0.1
OC	Tetrachloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	zero
IOC	Thallium	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories	0.0005
OC	Toluene	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories	1
M	Total Coliforms (including fecal coliform and *E. coli*)	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste.	zero
DBP	Total Trihalomethanes (TTHMs)	0.10 0.080 after 12/31/03	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection	n/a[6]
OC	Toxaphene	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle	zero
OC	2,4,5-TP (Silvex)	0.05	Liver problems	Residue of banned herbicide	0.05
OC	1,2,4-Trichlorobenzene	0.07	Changes in adrenal glands	Discharge from textile finishing factories	0.07
OC	1,1,1-Trichloroethane	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	0.20
OC	1,1,2-Trichloroethane	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories	0.003
OC	Trichloroethylene	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories	zero
M	Turbidity	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing micro-organisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff	n/a
R	Uranium	30 ug/L as of 12/08/03	Increased risk of cancer, kidney toxicity	Erosion of natural deposits	zero

LEGEND

D	Dinsinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

4

	Contaminant	MCL or TT[1] (mg/L)[2]	Potential health effects from exposure above the MCL	Common sources of contaminant in drinking water	Public Health Goal
OC	Vinyl chloride	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	zero
M	Viruses (enteric)	TT3	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero
OC	Xylenes (total)	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories	10

NOTES

1 Definitions

- Maximum Contaminant Level Goal (MCLG)—The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
- Maximum Contaminant Level (MCL)—The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
- Maximum Residual Disinfectant Level Goal (MRDLG)—The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
- Maximum Residual Disinfectant Level (MRDL)—The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
- Treatment Technique (TT)—A required process intended to reduce the level of a contaminant in drinking water.

2 Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (ppm).

3 EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- *Cryptosporidium* (as of 1/1/02 for systems serving >10,000 and 1/14/05 for systems serving <10,000) 99% removal.
- *Giardia lamblia*: 99.9% removal/inactivation
- Viruses: 99.99% removal/inactivation
- *Legionella:* No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.
- Turbidity: At no time can turbidity (cloudiness of water) go above 5 nephelolometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, for systems servicing >10,000, and January 14, 2005, for systems servicing <10,000, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
- HPC: No more than 500 bacterial colonies per milliliter
- Long Term 1 Enhanced Surface Water Treatment (Effective Date: January 14, 2005); Surface water systems or (GWUDI) systems serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (e.g. turbidity standards, individual filter monitoring, *Cryptosporidium* removal requirements, updated watershed control requirements for unfiltered systems).
- Filter Backwash Recycling: The Filter Backwash Recycling Rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.

4 No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive samples, and one is also positive for *E. coli* fecal coliforms, system has an acute MCL violation.

5 Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.

6 Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:

- Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.3 mg/L)
- Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L)

7 Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

8 Each water system must certify, in writing, to the state (using third-party or manufacturers certification) that when it uses acrylamide and/or epichlorohydrin to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: Acrylamide = 0.05% dosed at 1 mg/L (or equivalent); Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent).

LEGEND

D	Dinsinfectant	IOC	Inorganic Chemical	OC	Organic Chemical
DBP	Disinfection Byproduct	M	Microorganism	R	Radionuclides

APPENDIX III - Florida Soil Cleanup Target Levels

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Acenaphthene	83-32-9	2400	20000	2.1	0.3	0.3	21	-Liver	
Acenaphthylene	208-96-8	1800	20000	27	NA	NA	270	-Liver	
Acephate	30560-19-1	120	720	0.02	0.8	0.8	0.2	-Neurological	-yes
Acetaldehyde	75-07-0	15	20	NA	NA	NA	NA	-Nasal	
Acetone	67-64-1	11000	68000	25	6.8	6.8	250	-Kidney -Liver -Neurological	
Acetophenone	98-86-2	3900	32000	3.9	44	44	39	-None Specified	
Acifluorfen, sodium [or Blazer]	62476-59-9	28	140	0.1	25	25	1	-Kidney	
Acrolein	107-02-8	0.05	0.3	0.01	0.002	0.002	0.1	-Nasal	
Acrylamide	79-06-1	0.1	0.4	0.00003	0.001	0.001	0.0003	-Neurological	-yes
Acrylic acid	79-10-7	48	250	14	NA	NA	140	-Developmental	
Acrylonitrile	107-13-1	0.3	0.6	0.0003	0.001	0.001	0.003	-Nasal -Reproductive	-yes
Alachlor	15972-60-8	11	44	0.02	0.005	0.005	0.2	-Blood	-yes
Aldicarb [or Temik]	116-06-3	68	920	0.03	0.004	0.004	0.3	-Neurological	
Aldrin	309-00-2	0.06	0.3	0.2	0.01	0.01	2	-Liver	-yes
Ally [or Metsulfuron, methyl]	74223-64-6	19000	300000	12	NA	NA	120	-Body Weight	
Allyl alcohol	107-18-6	140	970	0.1	0.02	0.02	1	-Kidney -Liver	
Allyl chloride	107-05-1	0.5	2.7	0.2	NA	NA	2	-Neurological	

DISCLAIMER - For matters affecting legal rights or for the official version of cleanup target levels for Chapter 62-777, F.A.C., please refer to the F.A.W. published version of Chapter 62-777, F.A.C.

December 14, 2004

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Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Aluminum	7429-90-5	80000	*	***	***	***	***	-Body Weight	
Aluminum phosphide	20859-73-8	35	880	***	***	***	***	-Body Weight	
Ametryn	834-12-8	670	11000	0.8	0.08	0.08	8	-Liver	
Ammonia (a)	7664-41-7	35000	880000	***	***	NA	***	-Respiratory	
Aniline	62-53-3	27	150	0.03	0.02	0.02	0.3	-Blood -Spleen	-yes
Anthracene	120-12-7	21000	300000	2500	0.4	0.4	25000	-None Specified	
Antimony (b)	7440-36-0	27	370	5.4	3900	3900	54	-Blood	
Aroclor mixture [see PCBs]									
Arsenic	NOCAS	2.1	12	***	***	***	***	-Cardiovascular -Skin	-yes
Atrazine	1912-24-9	4.3	19	0.06	0.04	0.04	0.6	-Cardiovascular	-yes
Azinphos, methyl [see Guthion]									
Azobenzene	103-33-3	7.9	31	0.03	0.4	0.4	0.3		-yes
Barium (soluble salts) (b)	7440-39-3	120**	130000	1600	NA	NA	16000	-Cardiovascular	
Baygon [or Propoxur]	114-26-1	280	4100	0.2	0.002	0.002	2	-Blood -Neurological	
Bayleton	43121-43-3	2400	46000	4.8	11	11	48	-Blood	
Benomyl	17804-35-2	4000	77000	3.1	0.03	0.03	31	-Developmental	
Bentazon	25057-89-0	2100	32000	1.2	NA	NA	12	-Blood	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Benzaldehyde	100-52-7	3300	24000	4.8	0.4	0.4	48	-Gastrointestinal -Kidney	
Benzene	71-43-2	1.2	1.7	0.007	0.5	0.5	0.07	-Blood	-yes
Benzenethiol	108-98-5	0.2	1.3	0.001	NA	NA	0.01	-Liver	
Benzidine	92-87-5	0.004	0.02	0.00002	0.00002	0.00002	0.0002	-Liver -Neurological	-yes
Benzo(a)anthracene	56-55-3	#	#	0.8	NA	NA	8		-yes
Benzo(a)pyrene	50-32-8	0.1	0.7	8	NA	NA	80		-yes
Benzo(b)fluoranthene	205-99-2	#	#	2.4	NA	NA	24		-yes
Benzo(g,h,i)perylene	191-24-2	2500	52000	32000	NA	NA	320000	-Neurological	
Benzo(k)fluoranthene	207-08-9	#	#	24	NA	NA	240		-yes
Benzoic acid	65-85-0	180000	*	110	36	36	1100	-None Specified	
Benzotrichloride	98-07-7	0.04	0.09	0.0001	0.00008	0.00008	0.001		-yes
Benzyl alcohol	100-51-6	26000	670000	9.5	2.3	2.3	95	-Gastrointestinal	
Benzyl chloride	100-44-7	1	1.6	0.002	0.02	0.02	0.02		-yes
Beryllium (b)	7440-41-7	120	1400	63	2.1	2.1	630	-Gastrointestinal -Respiratory	-yes
Betanal [see Phenmedipham]									
BHC, alpha- [see Hexachlorocyclohexane, alpha-] (f)									
BHC, beta- [see Hexachlorocyclohexane, beta-] (f)									

Soil Cleanup Target Levels

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BHC, delta- [see Hexachlorocyclohexane, delta-] (f)									
BHC, gamma- [see Hexachlorocyclohexane, gamma-] (f)									
Bidrin [or Dicrotophos]	141-66-2	7.4	120	0.005	0.1	0.1	0.05	-Developmental	
Biphenyl, 1,1- [or Diphenyl]	92-52-4	3000	34000	0.2	5.8	5.8	2	-Kidney	
Bis(2-chloro-1-metylethyl)ether [see Bis(2-chloroisopropyl)ether]									
Bis(2-chloroethoxy)methane	111-91-1	250	5700	63	NA	NA	630	-Liver	
Bis(2-chloroethyl)ether	111-44-4	0.3	0.5	0.0001	0.002	0.002	0.001		-yes
Bis(2-chloroisopropyl)ether [or Bis(2-chloro-1-metylethyl)ether]	39638-32-9	6	12	0.009	0.4	0.4	0.09	-Blood	-yes
Bis(2-ethylhexyl)adipate	103-23-1	620	1900	780	64	64	7800	-Body Weight	-yes
Bis(2-ethylhexyl)phthalate [or DEHP]	117-81-7	72	390	3600	1300	1300	36000	-Liver	-yes
Bisphenol A	80-05-7	4000	79000	11	1.7	1.7	110	-Body Weight	
Blazer [see Acifluorfen, sodium]									
Boron	7440-42-8	17000	430000	***	NA	NA	***	-Reproductive -Respiratory	
Bravo [see Chlorothalonil]									
Bromacil	314-40-9	7500	120000	0.5	0.6	0.6	5	-Body Weight	
Bromate	15541-45-4	1	2.8	0.0002	NA	460	0.002	-Kidney	-yes
Bromochloromethane	74-97-5	95	530	0.6	NA	NA	6	-None Specified	

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Bromodichloromethane	75-27-4	1.5	2.2	0.004	0.1	0.1	0.04	-Kidney	-yes
Bromoform	75-25-2	48	93	0.03	2.7	2.7	0.3	-Liver	-yes
Bromomethane [or Methyl bromide]	74-83-9	3.1	16	0.05	0.2	0.2	0.5	-Gastrointestinal -Respiratory	
Bromoxynil	1689-84-5	1600	29000	3	NA	NA	30	-None Specified	
Butanol, n-	71-36-3	2900	21000	3	110	110	30	-Neurological	
Butanol, tert- [see Butyl alcohol, tert-]									
Butanone, 2- [see Methyl ethyl ketone]									
Butyl alcohol, tert- [or Butanol, tert-]	75-65-0	3200	19000	5.7	NA	NA	57	-Kidney -Neurological	
Butyl benzyl phthalate	85-68-7	17000	380000	310	56	56	3100	-Liver	
Butylate	2008-41-5	3200	40000	5.2	0.2	0.2	52	-Liver	
Butylphthalyl butylglycolate	85-70-1	84000	*	4200	NA	NA	42000	-None Specified	
Cadmium (b,c,h)	7440-43-9	82	1700	7.5	NA	14	75	-Kidney	-yes
Calcium cyanide	592-01-8	3500	88000	***	NA	NA	***	-Neurological -Thyroid	
Captafol	2425-06-1	110	570	0.5	0.1	0.1	5	-Kidney	-yes
Captan	133-06-2	230	750	0.1	0.03	0.03	1	-Body Weight	-yes
Carbaryl [or Sevin]	63-25-2	7700	130000	8.7	0.0007	0.0007	87	-Kidney -Liver	
Carbazole	86-74-8	49	240	0.2	6.5	6.5	2		-yes

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Carbofuran	1563-66-2	130	910	0.2	0.0006	0.0006	2	-Neurological -Reproductive	
Carbon disulfide	75-15-0	270	1500	5.6	0.8	0.8	56	-Developmental -Neurological	
Carbon tetrachloride	56-23-5	0.5	0.7	0.04	0.06	0.06	0.4	-Liver	-yes
Carbophenothion [or Trithion]	786-19-6	11	250	13	1.5	1.5	130	-Neurological	
Carboxin	5234-68-4	7400	120000	5	0.4	0.4	50	-Body Weight	
CFC 113 [see Trichloro-1,2,2-trifluoroethane, 1,1,2-]								-Adrenals	
Chloral hydrate	302-17-0	5700	62000	0.3	NA	NA	3	-Gastrointestinal -Neurological	
Chloramben	133-90-4	960	12000	0.5	NA	NA	5	-Liver	
Chlordane (total)	12789-03-6	2.8	14	9.6	0.003	0.003	96	-Liver	-yes
Chlorine cyanide [or Cyanogen chloride]	506-77-4	3100	37000	71	0.3	0.3	710	-Neurological -Thyroid	
Chloro-1,1-difluoroethane, 1-	75-68-3	16000	84000	NA	NA	NA	NA	-None Specified	
Chloro-1,3-butadiene [or Chloroprene]	126-99-8	3.5	19	1.5	NA	NA	15	-Hair Loss -Nasal	
Chloro-3-methylphenol, 4- [see Chloro-m-cresol, p-]									
Chloroacetic acid	79-11-8	130	1700	0.07	13	13	0.7	-Cardiovascular	
Chloroaniline, p-	106-47-8	270	3700	0.2	0.02	0.02	2	-Spleen	
Chlorobenzene	108-90-7	120	650	1.3	0.2	0.2	13	-Liver	
Chlorobenzilate	510-15-6	3.6	18	0.1	0.01	0.01	1	-Body Weight	-yes

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Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Chlorobenzoic acid, p-	74-11-3	16000	290000	28	NA	NA	280	-None Specified	
Chlorobenzotrifluoride, 4-	98-56-6	130	710	5.2	NA	NA	52	-Kidney	
Chlorobutane, 1-	109-69-3	780	4200	26	NA	NA	260	-Blood -Neurological	
Chlorodifluoromethane	75-45-6	16000	82000	NA	NA	NA	NA	-Adrenals -Kidney -Pituitary	
Chloroethane [see Ethyl chloride]									
Chloroform	67-66-3	0.4	0.6	0.4	2.8	2.8	4	-Liver	-yes
Chloro-m-cresol, p- [or Chloro-3-methylphenol, 4-]	59-50-7	600	8000	0.4	0.6	0.6	4	-Body Weight	
Chloromethane [see Methyl chloride]									
Chloronaphthalene, beta-	91-58-7	5000	61000	260	740	740	2600	-Liver -Respiratory	
Chloronitrobenzene, o-	88-73-3	22	51	0.02	NA	NA	0.2		-yes
Chloronitrobenzene, p-	100-00-5	31	73	0.03	1.6	1.6	0.3		-yes
Chlorophenol, 2-	95-57-8	130	860	0.7	2.5	2.5	7	-Reproductive	
Chlorophenol, 3-	108-43-0	370	5900	0.002	3.1	3.1	0.02	-Reproductive	
Chlorophenol, 4-	106-48-9	330	4400	0.0007	1.2	1.2	0.007	-Reproductive	
Chloroprene [see Chloro-1,3-butadiene]									
Chloropropane, 2-	75-29-6	47	250	NA	NA	NA	NA	-Liver	
Chlorothalonil [or Bravo]	1897-45-6	88	420	0.2	0.06	0.06	2	-Kidney	-yes

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Soil Cleanup Target Levels

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Chlorotoluene, o-	95-49-8	200	1200	2.8	7.7	7.7	28	-Body Weight	
Chlorotoluene, p-	106-43-4	170	990	2.5	NA	NA	25	-None Specified	
Chlorpropham	101-21-3	16000	310000	51	7	7	510	-Bone Marrow -Kidney -Liver -Spleen	
Chlorpyrifos	2921-88-2	250	5000	15	0.001	0.001	150	-Neurological	
Chromium (hexavalent) (b)	18540-29-9	210	470	NA	4.2	19	NA	-Respiratory	-yes
Chromium (total) (b,g)	NOCAS	210	470	38	4.2	19	380		-yes
Chromium (trivalent) (b)	16065-83-1	110000	*	NA	NA	*	NA	-None Specified	
Chrysene	218-01-9	#	#	77	NA	NA	770		-yes
Cobalt	7440-48-4	1700	42000	***	NA	NA	***	-Cardiovascular -Immunological -Neurological -	
Copper	7440-50-8	150**	89000	***	NA	***	***	-Gastrointestinal	
Coumaphos	56-72-4	21	450	0.3	0.0007	0.0007	3	-Neurological	
Cresol, m- [see Methylphenol, 3-]									
Cresol, o- [see Methylphenol, 2-]									
Cresol, p- [see Methylphenol, 4-]									
Crotonaldehyde	123-73-9	0.6	3.3	0.00008	NA	NA	0.0008		-yes
Cumene [or Isopropyl benzene]	98-82-8	220	1200	0.2	56	56	2	-Adrenals -Kidney	
Cyanide, free (b)	57-12-5	34**	11000	0.8	0.02	0.004	8	-Neurological -Thyroid	

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Cyanogen	460-19-5	560	3400	57	NA	NA	570	-Neurological -Thyroid	
Cyanogen chloride [see Chlorine cyanide]									
Cycloate	1134-23-2	340	4700	0.7	2.5	2.5	7	-Neurological	
Cyclohexanone	108-94-1	150000	*	150	110	110	1500		
Cyclohexylamine	108-91-8	18000	440000	7.9	22	22	79	-Reproductive	
Cyhalothrin [or Karate]	68085-85-8	420	9600	290	150	150	2900	-Developmental	
Cymene, p-	99-87-6	960	5600	NA	NA	NA	NA	-Gastrointestinal -Skin	
Cypermethrin	52315-07-8	840	19000	30	0.002	0.002	300	-Gastrointestinal	
DBCP, 1,2- [see Dibromo-3-chloropropane, 1,2-]									
DDD, 4,4'- [see Dichlorodiphenyldichloroethane, p,p']									
DDE, 4,4'- [see Dichlorodiphenyldichloroethylene, p,p'-]									
DDT, 4,4'- [see Dichlorodiphenyltrichloroethane, p,p'-]									
Decabromodiphenyl ether	1163-19-5	840	19000	9.3	NA	NA	93	-None Specified	
DEHP [see Bis(2-ethylhexyl)phthalate]									
Diallate	2303-16-4	16	82	0.6	NA	NA	6	-None Specified	-yes
Diazinon	333-41-5	70	1200	0.2	0.00005	0.00005	2	-Neurological	
Dibenz(a,h)anthracene	53-70-3	#	#	0.7	NA	NA	7		-yes

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Dibenzofuran	132-64-9	320	6300	15	36	36	150	-None Specified	
Dibromo-3-chloropropane, 1,2- [or DBCP, 1,2-]	96-12-8	0.7	3.8	0.001	NA	NA	0.01	-Reproductive	-yes
Dibromobenzene, 1,4-	106-37-6	430	3600	7.8	27	27	78	-Liver	
Dibromochloromethane	124-48-1	1.5	2.3	0.003	0.2	0.2	0.03	-Liver	-yes
Dibromoethane, 1,2- [or EDB]	106-93-4	0.1	0.2	0.0001	0.07	0.07	0.001	-Reproductive	-yes
Dibutyl phthalate	84-74-2	8200	170000	47	1.5	1.5	470	-Mortality	
Dicamba	1918-00-9	2300	40000	2.6	2.4	2.4	26	-Developmental	
Dichloroacetic acid	79-43-6	21	120	0.005	8.1	8.1	0.05	-Liver -Neurological -Reproductive	-yes
Dichloroacetonitrile	3018-12-0	340	2900	0.03	NA	NA	0.3	-None Specified	
Dichlorobenzene, 1,2-	95-50-1	880	5000	17	2.8	2.8	170	-Body Weight	
Dichlorobenzene, 1,3-	541-73-1	380	2200	7	2.8	2.8	70	-None Specified	
Dichlorobenzene, 1,4-	106-46-7	6.4	9.9	2.2	0.09	0.09	22	-Liver	-yes
Dichlorobenzidine, 3,3'-	91-94-1	2.1	9.9	0.003	0.0009	0.0009	0.03		-yes
Dichlorobenzophenone, 4,4'-	90-98-2	2500	51000	25	190	190	250	-None Specified	
Dichlorodifluoromethane	75-71-8	77	410	44	NA	NA	440	-Liver	
Dichlorodiphenyldichloroethane, p,p'- [or DDD, 4,4'-]	72-54-8	4.2	22	5.8	0.01	0.01	58		-yes
Dichlorodiphenyldichloroethylene, p,p'- [or DDE, 4,4'-]	72-55-9	2.9	15	18	0.04	0.04	180		-yes

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Dichlorodiphenyltrichloroethane, p,p'- [or DDT, 4,4'-]	50-29-3	2.9	15	11	0.06	0.06	110	-Liver	-yes
Dichloroethane, 1,1-	75-34-3	390	2100	0.4	NA	NA	4	-Kidney	
Dichloroethane, 1,2- [or EDC]	107-06-2	0.5	0.7	0.01	0.2	0.2	0.1	-None Specified	-yes
Dichloroethene, 1,1-	75-35-4	95	510	0.06	0.03	0.03	0.6	-Liver	
Dichloroethene, cis-1,2-	156-59-2	33	180	0.4	NA	NA	4	-Blood	
Dichloroethene, trans-1,2-	156-60-5	53	290	0.7	75	75	7	-Blood -Liver	
Dichlorophenol, 2,3-	576-24-9	230	4100	0.0008	1.2	1.2	0.008	-Immunological	
Dichlorophenol, 2,4-	120-83-2	190	2400	0.003	0.1	0.1	0.03	-Immunological	
Dichlorophenol, 2,5-	583-78-8	240	4600	0.02	4.3	4.3	0.2	-Immunological	
Dichlorophenol, 2,6-	87-65-0	220	3600	0.007	2.5	2.5	0.07	-Immunological	
Dichlorophenol, 3,4-	95-77-2	230	3700	0.01	2	2	0.1	-Immunological	
Dichlorophenoxy acetic acid, 2,4-	94-75-7	770	13000	0.7	0.9	0.9	7	-Blood -Kidney -Liver	
Dichloropropane, 1,2-	78-87-5	0.6	0.9	0.03	0.09	0.09	0.3	-Nasal	-yes
Dichloropropene, 1,3-	542-75-6	1.4	2.2	0.002	0.09	0.09	0.02	-Gastrointestinal -Nasal	-yes
Dichlorprop	120-36-5	370	5800	0.3	0.3	0.3	3	-None Specified	
Dichlorvos	62-73-7	0.3	0.4	0.0006	0.00002	0.00002	0.006	-Neurological	-yes
Dicofol [or Kelthane]	115-32-2	2.2	11	0.01	0.0008	0.0008	0.1	-Adrenals	-yes

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Dicrotophos [see Bidrin]									
Dieldrin	60-57-1	0.06	0.3	0.002	0.0001	0.0001	0.02	-Liver	-yes
Diethyl phthalate	84-66-2	61000	*	86	5.9	5.9	860	-Body Weight	
Diethylene glycol, monoethyl ether	111-90-0	130000	*	63	750	750	630	-Kidney	
Diisopropyl methylphosphonate	1445-75-6	4500	49000	3.6	85	85	36	-None Specified	
Dimethoate	60-51-5	13	170	0.006	0.0004	0.0004	0.06	-Neurological	
Dimethoxybenzidine, 3,3'-	119-90-4	69	330	0.2	NA	NA	2		-yes
Dimethrin	70-38-2	24000	440000	2500	1.3	1.3	25000	-Liver	
Dimethylaniline, 2,4-	95-68-1	0.5	1	0.0005	19	19	0.005	-Blood -Spleen	-yes
Dimethylaniline, N,N-	121-69-7	55	380	0.1	12	12	1	-Spleen	
Dimethylbenzidine, 3,3'-	119-93-7	0.1	0.6	0.001	NA	NA	0.01		-yes
Dimethylformamide, N,N-	68-12-2	1400	8600	3	210	210	30	-Gastrointestinal -Liver	
Dimethylphenol, 2,4-	105-67-9	1300	18000	1.7	1.9	1.9	17	-Blood -Neurological	
Dimethylphenol, 2,6-	576-26-1	34	370	0.04	5.2	5.2	0.4	-Kidney -Liver -Spleen	
Dimethylphenol, 3,4-	95-65-8	71	1000	0.06	3.4	3.4	0.6	-Kidney -Liver -Spleen	
Dimethylphthalate	131-11-3	690000	*	380	7.8	7.8	3800	-Kidney	
Dinitrobenzene, 1,2- (o)	528-29-0	23	240	0.01	0.2	0.2	0.1	-Spleen	

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Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Dinitrobenzene, 1,3- (m)	99-65-0	5.8	64	0.004	0.4	0.4	0.04	-Spleen	
Dinitrobenzene, 1,4- (p)	100-25-4	35	890	0.04	0.4	0.4	0.4	-Spleen	
Dinitro-o-cresol, 4,6-	534-52-1	8.4	180	0.4	NA	NA	4	-Metabolic Disorders	
Dinitrophenol, 2,4-	51-28-5	110	1200	0.06	0.01	0.01	0.6	-Eye	
Dinitrotoluene, 2,4-	121-14-2	1.2	4.3	0.0004	0.07	0.07	0.004	-Liver -Neurological	-yes
Dinitrotoluene, 2,6-	606-20-2	1.2	3.8	0.0004	0.005	0.005	0.004	-Blood -Kidney -Neurological	-yes
Di-n-octylphthalate	117-84-0	1700	39000	480000	NA	NA	4800000	-Kidney -Liver	
Dinoseb	88-85-7	65	840	0.03	0.03	0.03	0.3	-Developmental	
Dioxane, 1,4-	123-91-1	23	38	0.01	0.5	0.5	0.1		-yes
Dioxins, as total 2,3,7,8-TCDD equivalents (e)	1746-01-6	0.000007	0.00003	0.003	0.0000006	0.0000006	0.03		-yes
Diphenamid	957-51-7	2300	41000	2.6	20	20	26	-Liver	
Diphenyl [see Biphenyl, 1,1-]									
Diphenylamine, N,N-	122-39-4	2000	40000	14	NA	NA	140	-Kidney -Liver	
Diphenylhydrazine, 1,2-	122-66-7	1.1	4.8	0.002	0.007	0.007	0.02		-yes
Diquat	85-00-7	190	4300	800	60	60	8000	-Eye	
Disulfoton	298-04-4	3.3	66	0.09	0.1	0.1	0.9	-Neurological	
Diuron	330-54-1	150	2300	0.3	0.2	0.2	3	-Blood	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure: Residential (mg/kg)	Direct Exposure: Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
EDB [see Dibromoethane, 1,2-]									
EDC [see Dichloroethane, 1,2-]									
Endosulfan (alpha+beta+sulfate)	115-29-7	450	7600	3.8	0.005	0.0008	38	-Cardiovascular -Kidney	
Endothall	145-73-3	1800	44000	0.4	0.4	0.4	4	-Gastrointestinal	
Endrin	72-20-8	25	510	1	0.001	0.001	10	-Liver	
EPEG [see Ethylphthalyl ethylglycolate]									
Epichlorohydrin	106-89-8	14	80	0.03	1.1	1.1	0.3	-Kidney -Nasal	-yes
EPN [see Ethyl p-nitrophenyl phenylphosphorothioate]									
EPTC [see Ethyl dipropylthiocarbamate, S-]									
Ethanol	64-17-5	*	*	40	NA	NA	400	-Developmental	
Ethion	563-12-2	42	920	1.7	0.003	0.003	17	-Neurological	
Ethoprop	13194-48-4	7.4	120	0.005	0.002	0.002	0.05	-Neurological	
Ethoxyethanol acetate, 2-	111-15-9	14000	130000	8.8	8.4	8.4	88	-Developmental	
Ethoxyethanol, 2-	110-80-5	10000	72000	13	NA	NA	130	-Reproductive	
Ethyl acetate	141-78-6	9100	53000	26	26	26	260	-Body Weight	
Ethyl acrylate	140-88-5	2	3	0.002	0.6	0.6	0.02		-yes
Ethyl chloride [or Chloroethane]	75-00-3	3.9	5.4	0.06	NA	NA	0.6	-Developmental	-yes

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure: Residential (mg/kg)	Direct Exposure: Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Ethyl dipropylthiocarbamate, S- [or EPTC]	759-94-4	1400	14000	11	15	15	110	-Cardiovascular	
Ethyl ether	60-29-7	260	1400	5	850	850	50	-Body Weight	
Ethyl methacrylate	97-63-2	630	3500	3.5	NA	NA	35	-Kidney	
Ethyl p-nitrophenyl phenylphosphorothioate [or EPN]	2104-64-5	0.8	18	0.02	0.003	0.003	0.2	-Neurological	
Ethylbenzene	100-41-4	1500	9200	0.6	12	12	6	-Developmental -Kidney -Liver	
Ethylene diamine	107-15-3	1100	11000	0.6	3.2	3.2	6	-Blood -Cardiovascular	
Ethylene glycol	107-21-1	110000	*	56	65	65	560	-Kidney	
Ethylene oxide	75-21-8	0.3	0.4	0.0002	20	20	0.002		-yes
Ethylene thiourea [or ETU]	96-45-7	7	57	0.001	5.6	5.6	0.01	-Thyroid	-yes
Ethylphthalyl ethylglycolate [or EPEG]	84-72-0	260000	*	1200	NA	NA	12000	-Kidney	
ETU [see Ethylene thiourea]									
Fenamiphos	22224-92-6	19	340	0.02	0.003	0.003	0.2	-Neurological	
Fensulfothion	115-90-2	19	310	0.01	0.004	0.004	0.1	-Neurological	
Fenvalerate [see Pydrin]									
Fluometuron	2164-17-2	980	16000	0.9	1.8	1.8	9	-None Specified	
Fluoranthene	206-44-0	3200	59000	1200	1.3	1.3	12000	-Blood -Kidney -Liver	
Fluorene	86-73-7	2600	33000	160	17	17	1600	-Blood	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Fluoride	7782-41-4	840**	130000	6000	30000	15000	60000	-Teeth mottling	
Fluoridone	59756-60-4	7000	180000	2500	460	460	25000	-Kidney -Reproductive	
Fonofos	944-22-9	140	2100	0.4	0.003	0.003	4	-Liver -Neurological	
Formaldehyde	50-00-0	23	31	2.4	0.4	0.4	24	-Gastrointestinal	-yes
Furan	110-00-9	4.8	26	0.09	NA	NA	0.9	-Liver	
Furfural	98-01-1	190	2400	0.09	2.7	2.7	0.9	-Liver -Nasal	
Glycidaldehyde	765-34-4	15	120	0.01	NA	NA	0.1	-Adrenals -Blood -Kidney	
Glyphosate [or Roundup]	1071-83-6	8800	220000	3.3	0.5	0.5	33	-Kidney	
Guthion [or Methyl azinphos]	86-50-0	120	2400	0.2	0.0002	0.0002	2	-Neurological	
Heptachlor	76-44-8	0.2	1	23	0.01	0.01	230	-Liver	-yes
Heptachlor epoxide	1024-57-3	0.1	0.5	0.6	0.0001	0.0001	6	-Liver	-yes
Hexachloro-1,3-butadiene	87-68-3	6.2	13	1	110	110	10	-Kidney	-yes
Hexachlorobenzene	118-74-1	0.4	1.2	2.2	0.0006	0.0006	22	-Liver	-yes
Hexachlorocyclohexane, alpha- [or BHC, alpha-]	319-84-6	0.1	0.6	0.0003	0.0003	0.0003	0.003		-yes
Hexachlorocyclohexane, beta- [BHC, beta-]	319-85-7	0.5	2.4	0.001	0.003	0.003	0.01		-yes
Hexachlorocyclohexane, delta- [or BHC, delta-]	319-86-8	24	490	0.2	NA	NA	2	-Kidney -Liver	
Hexachlorocyclohexane, gamma- [or Lindane or BHC, gamma-]	58-89-9	0.7	2.5	0.009	0.003	0.003	0.09	-Kidney -Liver	-yes

Soil Cleanup Target Levels

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Hexachlorocyclopentadiene	77-47-4	9.5	50	400	24	24	4000	-Gastrointestinal	
Hexachloroethane	67-72-1	38	87	0.2	0.2	0.2	2	-Kidney	-yes
Hexachlorophene	70-30-4	26	670	53	26	26	530	-Neurological	
Hexahydro-1,3,5-trinitro-1,3,5-triazine [or RDX]	121-82-4	7.7	28	0.002	1.3	1.3	0.02	-Reproductive	-yes
Hexane, n-	110-54-3	680	3900	2.1	1200	1200	21	-Neurological	
Hexanone, 2- [or Methyl butyl ketone]	591-78-6	24	130	1.4	NA	NA	14	-None Specified	
Hexazinone	51235-04-2	2300	32000	1.1	120	120	11	-Body Weight	
Hydroquinone	123-31-9	2600	35000	1.4	0.02	0.02	14	-Blood	
Indeno(1,2,3-cd)pyrene	193-39-5	#	#	6.6	NA	NA	66		-yes
Iron	7439-89-6	53000	*	***	***	***	***	-Gastrointestinal	
Isobutyl alcohol	78-83-1	6400	42000	8.9	200	200	89	-Neurological	
Isophorone	78-59-1	540	1200	0.2	3.8	3.8	2	-None Specified	-yes
Isopropyl benzene [see Cumene]									
Karate [see Cyhalothrin, lambda]									
Kelthane [see Dicofol]									
Lead (d)	7439-92-1	400	1400	***	NA	***	***	-Neurological	
Limonene	138-86-3	640	3600	42	NA	NA	420	-Kidney -Liver	

Soil Cleanup Target Levels

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Lindane [see Hexachlorocyclohexane, gamma-]									
Linuron	330-55-2	160	3100	0.04	1.4	1.4	0.4	-Blood	
Lithium	7439-93-2	1700	44000	***	NA	NA	***	-None Specified	
Malathion	121-75-5	1500	24000	4.2	0.003	0.003	42	-Neurological	
Maleic anhydride	108-31-6	3200	24000	2.8	NA	NA	28	-Kidney	
Maleic hydrazide	123-33-1	1000	5400	16	3.4	3.4	160	-Kidney	
Malonitrile	109-77-3	1.2	13	0.0006	NA	NA	0.006	-Liver -Spleen	
Maneb	12427-38-2	410	8400	2.9	0.5	0.5	29	-Thyroid	
Manganese	7439-96-5	3500	43000	***	NA	NA	***	-Neurological	
MCPA [see Methyl-4-chlorophenoxy acetic acid, 2-]									
MCPP [see Propionic acid, 2-(2-methyl-4-chlorophenoxy)]									
Mercury (c)	7439-97-6	3	17	2.1	0.01	0.03	21	-Neurological	
Mercury, methyl- [see Methylmercury]									
Merphos	150-50-5	2.5	52	0.5	NA	NA	5	-Neurological	
Merphos oxide	78-48-8	2.5	56	0.3	0.3	0.3	3	-Neurological	
Methacrylonitrile	126-98-7	1	5.9	0.003	NA	NA	0.03	-Liver	
Methamidophos	10265-92-6	3.1	36	0.001	0	0	0.01	-Neurological	

Soil Cleanup Target Levels

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Methanol	67-56-1	13000	90000	14	180	180	140	-Developmental -Eye -Neurological	
Methidathion	950-37-8	68	950	0.003	0.0001	0.0001	0.03	-Liver	
Methomyl	16752-77-5	38	200	1.2	0.007	0.007	12	-Kidney -Spleen	
Methoxy-5-nitroaniline, 2-	99-59-2	19	71	0.006	NA	NA	0.06		-yes
Methoxychlor	72-43-5	420	8800	160	0.1	0.1	1600	-Developmental -Reproductive	
Methyl acetate	79-20-9	6800	38000	16	NA	NA	160	-Liver	
Methyl acrylate	96-33-3	260	1500	0.9	NA	NA	9	-None Specified	
Methyl azinphos [see Guthion]									
Methyl bromide [see Bromomethane]									
Methyl butyl ketone [see Hexanone, 2-]									
Methyl chloride [or Chloromethane]	74-87-3	4	5.7	0.01	2.3	2.3	0.1	-Neurological	-yes
Methyl chloroform [see Trichloroethane, 1,1,1-]									
Methyl ethyl ketone [or Butanone, 2-]	78-93-3	16000	110000	17	490	490	170	-Developmental	
Methyl isobutyl ketone [or MIBK]	108-10-1	4300	44000	2.6	110	110	26	-Kidney -Liver	
Methyl methacrylate	80-62-6	1900	10000	0.1	32	32	1	-Nasal	
Methyl parathion [or Parathion, methyl]	298-00-0	20	370	0.06	0.0003	0.0003	0.6	-Blood -Neurological	
Methyl styrene (mixed)	25013-15-4	120	770	0.8	NA	NA	8	-Nasal	

Soil Cleanup Target Levels

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Methyl styrene, alpha	98-83-9	1500	10000	11	NA	NA	110	-Kidney -Liver	
Methyl tert-butyl ether [or MTBE]	1634-04-4	4400	24000	0.09	150	150	0.9	-Eye -Kidney -Liver	
Methyl-4-chlorophenoxy acetic acid, 2- [or MCPA]	94-74-6	35	500	0.02	0.4	0.4	0.2	-Kidney -Liver	
Methylaniline, 2-	95-53-4	2.6	6.4	0.0009	0.2	0.2	0.009		-yes
Methylene bis(2-chloroaniline), 4,4-	101-14-4	6.4	23	0.001	NA	NA	0.01	-Liver -Bladder	-yes
Methylene bromide	74-95-3	96	550	0.3	NA	NA	3	-Blood	
Methylene chloride	75-09-2	17	26	0.02	7.3	7.3	0.2	-Liver	-yes
Methylene diphenyl diisocyanate	101-68-8	400	2100	NA	NA	NA	NA	-Nasal	
Methylmercury [or Mercury, methyl]	22967-92-6	1.1	6.1	0.002	NA	NA	0.02	-Neurological	
Methylnaphthalene, 1-	90-12-0	200	1800	3.1	10	10	31	-Nasal	
Methylnaphthalene, 2-	91-57-6	210	2100	8.5	9.1	9.1	85	-Nasal	
Methylphenol, 2- [or Cresol, o-]	95-48-7	2900	31000	0.3	1.9	1.9	3	-Neurological	
Methylphenol, 3- [or Cresol, m-]	108-39-4	2900	33000	0.3	3.3	3.3	3	-Neurological	
Methylphenol, 4- [or Cresol, p-]	106-44-5	300	3400	0.03	0.5	0.5	0.3	-Neurological -Respiratory	
Metolachlor	51218-45-2	12000	200000	1.2	0.01	0.01	12	-Body Weight	
Metribuzin	21087-64-9	54	290	2.2	0.8	0.8	22	-Kidney -Liver	
Metsulfuron, methyl [see Ally]									

Soil Cleanup Target Levels

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Mevinphos	7786-34-7	18	270	0.01	0.0003	0.0003	0.1	-Neurological	
MIBK [see Methyl isobutyl ketone]									
Molinate	2212-67-1	120	1300	0.1	0.1	0.1	1	-Reproductive	
Molybdenum	7439-98-7	440	11000	***	NA	NA	***	-Gout	
MTBE [see Methyl tert-butyl ether]									
Naled	300-76-5	150	2400	0.1	0.0002	0.0002	1	-Neurological	
Naphthalene	91-20-3	55	300	1.2	2.2	2.2	12	-Nasal	
Nickel (b,c)	7440-02-0	340**	35000	130	NA	11	1300	-Body Weight	
Nitrate	14797-55-8	140000	*	***	NA	NA	***	-Blood	
Nitrite	14797-65-0	8700	220000	***	NA	NA	***	-Blood	
Nitroaniline, m-	99-09-2	21	130	0.01	NA	NA	0.1	-Blood	-yes
Nitroaniline, o-	88-74-4	24	130	0.1	NA	NA	1	-Blood	
Nitroaniline, p-	100-01-6	17	96	0.008	5.9	5.9	0.08	-Blood	-yes
Nitrobenzene	98-95-3	18	140	0.02	0.6	0.6	0.2	-Adrenals -Blood -Kidney -Liver	
Nitroglycerin	55-63-0	27	54	0.03	NA	NA	0.3	-Cardiovascular	-yes
Nitrophenol, 4-	100-02-7	560	7900	0.3	0.3	0.3	3	-None Specified	
Nitroso-di-ethylamine, N-	55-18-5	0.003	0.005	0.000001	0.00003	0.00003	0.00001		-yes

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Nitroso-dimethylamine, N-	62-75-9	0.009	0.02	0.000003	0.01	0.01	0.00003		-yes
Nitroso-di-n-butylamine, N-	924-16-3	0.05	0.08	0.00009	0.0005	0.0005	0.0009		-yes
Nitroso-di-n-propylamine, N-	621-64-7	0.08	0.2	0.00005	0.005	0.005	0.0005		-yes
Nitroso-diphenylamine, N-	86-30-6	180	730	0.4	0.3	0.3	4		-yes
Nitroso-N-methylethylamine, N-	10595-95-6	0.02	0.04	0.000006	0.0002	0.0002	0.00006		-yes
Nitrotoluene, m-	99-08-1	640	4700	1.4	3.6	3.6	14	-Spleen	
Nitrotoluene, o-	88-72-2	400	3300	0.9	7.3	7.3	9	-Spleen	
Nitrotoluene, p-	99-99-0	750	12000	0.9	7.3	7.3	9	-Spleen	
Nonylphenol	25154-52-3	100	2200	20	14	3.4	200	-Kidney	
Octamethylpyrophosphoramide	152-16-9	130	1600	0.06	NA	NA	0.6	-Neurological	
Oxamyl	23135-22-0	1700	22000	0.9	0.04	0.04	9	-Body Weight	
Paraquat	1910-42-5	340	5500	16	230	230	160	-Respiratory	
Parathion	56-38-2	500	11000	1	0.01	0.01	10	-Neurological	
Parathion, methyl [see Methyl parathion]									
PCBs [or Aroclor mixture]	1336-36-3	0.5	2.6	17	0.002	0.002	170	-Immunological	-yes
PCE [see Tetrachloroethene]									
Pebulate	1114-71-2	2000	17000	8.5	7.4	7.4	85	-Blood	

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Pendimethalin	40487-42-1	3200	58000	28	1	1	280	-Liver	
Pentachlorobenzene	608-93-5	45	480	3.9	1.2	1.2	39	-Kidney -Liver	
Pentachloronitrobenzene	82-68-8	3.3	12	0.2	0.03	0.03	2	-Liver	-yes
Pentachlorophenol	87-86-5	7.2	28	0.03	0.2	0.2	0.3	-Kidney -Liver	-yes
Permethrin	52645-53-1	4200	96000	2500	0.007	0.007	25000	-Liver	
Phenanthrene	85-01-8	2200	36000	250	NA	NA	2500	-Kidney	
Phenmedipham [or Betanal]	13684-63-4	21000	450000	150	18	18	1500	-None Specified	
Phenol	108-95-2	500**	220000	0.05	0.03	0.03	0.5	-Developmental	
Phenylenediamine, m-	108-45-2	360	4000	0.2	NA	NA	2	-Liver	
Phenylenediamine, o-	95-54-5	17	54	0.004	NA	NA	0.04		-yes
Phenylenediamine, p-	106-50-3	12000	160000	6.2	NA	NA	62	-Whole Body	
Phenylphenol, 2-	90-43-7	490	2100	0.4	0.8	0.8	4		-yes
Phorate	298-02-2	16	320	0.3	0.001	0.001	3	-Neurological	
Phosmet	732-11-6	1600	33000	5	0.004	0.004	50	-Liver -Neurological	
Phthalic acid, p-	100-21-0	8000	45000	110	NA	NA	1100	-Bladder	
Phthalic anhydride	85-44-9	11000	63000	76	NA	NA	760	-Kidney -Nasal -Respiratory	
Polychlorinated dibenzo-p-dioxins [see Dioxins]									

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure		Leachability Based on Groundwater Criteria	Leachability Based on Freshwater Surface Water Criteria	Leachability Based on Marine Surface Water Criteria	Leachability Based on Groundwater of Low Yield/ Poor Quality	Target Organs/Systems or Effects†	Carcinogen
		Residential (mg/kg)	Commercial/ Industrial (mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)		
Prometon	1610-18-0	1200	23000	2.4	14	14	24	-None Specified	
Prometryn	7287-19-6	320	6100	0.7	0.5	0.5	7	-Bone Marrow -Kidney -Liver	
Propachlor	1918-16-7	990	17000	1.1	0.1	0.1	11	-Liver	
Propanil	709-98-8	390	6700	0.4	0.2	0.2	4	-Spleen	
Propazine	139-40-2	1600	28000	0.2	2.7	2.7	2	-Body Weight	
Propionic acid, 2-(2-methyl-4-chlorophenoxy) [or MCPP]	93-65-2	64	800	0.03	NA	NA	0.3	-Kidney	
Propoxur [see Baygon]									
Propylene glycol	57-55-6	*	*	560	140	140	5600	-Blood -Bone Marrow	
Propylene glycol monomethyl ether	107-98-2	38000	390000	20	NA	NA	200	-Kidney -Liver -Neurological	
Propylene oxide	75-56-9	3.1	9.3	0.0006	NA	NA	0.006	-Nasal -Respiratory	-yes
Pydrin [or Fenvalerate]	51630-58-1	2100	46000	70	0.0001	0.0001	700	-Neurological	
Pyrene	129-00-0	2400	45000	880	1.3	1.3	8800	-Kidney	
Pyridine	110-86-1	20	130	0.03	5.4	5.4	0.3	-Liver	
Quinoline	91-22-5	0.3	1.3	0.0009	NA	NA	0.009		-yes
RDX [see Hexahydro-1,3,5-trinitro-1,3,5-triazine]									
Resmethrin	10453-86-8	2500	56000	1200	0.01	0.01	12000	-Reproductive	
Ronnel	299-84-3	4200	88000	1300	0.2	0.2	13000	-Liver	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure		Leachability Based on Groundwater Criteria	Leachability Based on Freshwater Surface Water Criteria	Leachability Based on Marine Surface Water Criteria	Leachability Based on Groundwater of Low Yield/ Poor Quality	Target Organs/Systems or Effects†	Carcinogen
		Residential (mg/kg)	Commercial/ Industrial (mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)		
Roundup [see Glyphosate]									
Selenium (b,c)	7782-49-2	440	11000	5.2	0.5	7.4	52	-Hair Loss -Neurological -Skin	
Sevin [see Carbaryl]									
Silver (b)	7440-22-4	410	8200	17	0.01	0.06	170	-Skin	
Silvex [see Trichlorophenoxy propionic acid]									
Simazine	122-34-9	7.8	35	0.08	0.1	0.1	0.8	-Blood	-yes
Strontium	7440-24-6	52000	*	***	NA	NA	***	-Bone	
Strychnine	57-24-9	23	380	0.02	0.3	0.3	0.2	-Mortality	
Styrene	100-42-5	3600	23000	3.6	16	16	36	-Blood -Liver -Neurological	
TCDD, 2,3,7,8- [see Dioxins, as total 2,3,7,8-TCDD equivalents]									
TCE [see Trichloroethene]									
Temik [see Aldicarb]									
Terbacil	5902-51-2	920	14000	0.5	14	14	5	-Liver -Thyroid	
Terbufos	13071-79-9	1.9	29	0.02	0.001	0.001	0.2	-Neurological	
Terbutryn	886-50-0	88	2200	0.2	0.09	0.09	2	-Blood	
Tetrachlorobenzene, 1,2,4,5-	95-94-3	12	100	0.5	0.4	0.4	5	-Kidney	
Tetrachloroethane, 1,1,1,2-	630-20-6	2.9	4.3	0.01	NA	NA	0.1	-Kidney -Liver	-yes

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Tetrachloroethane, 1,1,2,2-	79-34-5	0.7	1.2	0.001	0.08	0.08	0.01	-Liver	-yes
Tetrachloroethene [or PCE]	127-18-4	8.8	18	0.03	0.1	0.1	0.3	-Liver	-yes
Tetrachlorophenol, 2,3,4,6-	58-90-2	2100	30000	3.2	0.07	0.07	32	-Liver	
Tetraethyl dithiopyrophosphate	3689-24-5	35	510	0.1	0.0004	0.0004	1	-Bone Marrow -Neurological	
Thallium	7440-28-0	6.1	150	2.8	9	9	28	-Hair Loss -Liver	
Thiobencarb	28249-77-6	810	16000	2.9	NA	NA	29	-Kidney	
Thiram	137-26-8	400	7700	1.1	0.005	0.005	11	-Neurological	
Tin	7440-31-5	47000	880000	***	NA	NA	***	-Kidney -Liver	
Toluene	108-88-3	7500	60000	0.5	5.6	5.6	5	-Kidney -Liver -Neurological	
Toluene diisocyanate, 2,4/2,6- mixture	26471-62-5	1.3	15	NA	NA	NA	NA	-Respiratory	
Toluidine, p-	106-49-0	2.2	4.5	0.0009	NA	NA	0.009		-yes
Toxaphene	8001-35-2	0.9	4.5	31	0.002	0.002	310	-Developmental	-yes
Triallate	2303-17-5	980	16000	8.4	6	6	84	-Liver -Spleen	
Tributyltin oxide	56-35-9	25	570	7.6	0.2	0.2	76	-Immunological	
Trichloro-1,2,2-trifluoroethane, 1,1,2- [or CFC 113]	76-13-1	18000	96000	11000	NA	NA	110000	-Neurological	
Trichloroacetic acid	76-03-9	770	8800	0.04	400	400	0.4	-None Specified	
Trichlorobenzene, 1,2,3-	87-61-6	650	8200	4.6	5.6	5.6	46	-Adrenals	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure Residential (mg/kg)	Direct Exposure Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Trichlorobenzene, 1,2,4-	120-82-1	660	8500	5.3	1.7	1.7	53	-Adrenals	
Trichlorobenzene, 1,3,5-	108-70-3	260	2300	16	NA	NA	160	-None Specified	
Trichloroethane, 1,1,1- [or Methyl chloroform]	71-55-6	730	3900	1.9	2.6	2.6	19	-None Specified	
Trichloroethane, 1,1,2-	79-00-5	1.4	2	0.03	0.09	0.09	0.3	-Liver	-yes
Trichloroethene [or TCE]	79-01-6	6.4	9.3	0.03	0.9	0.9	0.3	-None Specified	-yes
Trichlorofluoromethane	75-69-4	270	1500	33	NA	NA	330	-Cardiovascular -Kidney -Respiratory	
Trichlorophenol, 2,4,5-	95-95-4	7700	130000	0.07	1.5	1.5	0.7	-Kidney -Liver	
Trichlorophenol, 2,4,6-	88-06-2	70	230	0.06	0.1	0.1	0.6		-yes
Trichlorophenoxy acetic acid, 2,4,5-	93-76-5	690	9500	0.4	0.8	0.8	4	-Kidney	
Trichlorophenoxy propionic acid, 2, (2, 4, 5-) [or Silvex]	93-72-1	660	14000	5.4	NA	NA	54	-Liver	
Trichloropropane, 1,1,2-	598-77-6	76	460	0.3	NA	NA	3	-Kidney -Liver -Thyroid	
Trichloropropane, 1,2,3-	96-18-4	0.06	0.1	0.0001	0.001	0.001	0.001	-Kidney -Liver	-yes
Trichloropropene, 1,2,3-	96-19-5	18	98	0.4	NA	NA	4	-Eye	
Triethylamine	121-44-8	41	270	NA	NA	NA	NA	-Nasal	
Trifluralin	1582-09-8	92	280	3.6	0.2	0.2	36	-Blood -Liver	-yes
Trimethyl phosphate	512-56-1	19	57	0.004	NA	NA	0.04		-yes
Trimethylbenzene, 1,2,3-	526-73-8	18	96	0.3	NA	NA	3	-None Specified	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure: Residential (mg/kg)	Direct Exposure: Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen
Trimethylbenzene, 1,2,4-	95-63-6	18	95	0.3	7.2	7.2	3	-None Specified	
Trimethylbenzene, 1,3,5-	108-67-8	15	80	0.3	6.7	6.7	3	-None Specified	
Trinitrobenzene, 1,3,5-	99-35-4	2000	26000	1	0.09	0.09	10	-Blood -Spleen	
Trinitrophenylmethylnitramine	479-45-8	790	15000	1.4	NA	NA	14	-Kidney -Liver -Spleen	
Trinitrotoluene, 2,4,6-	118-96-7	28	97	0.006	0.3	0.3	0.06	-Liver	-yes
Trithion [see Carbophenothion]									
TRPH	NOCAS	460	2700	340	340	340	3400	-Multiple Endpoints Mixed Contaminants	
Uranium, soluble salts	7440-61-1	110	820	***	NA	NA	***	-Kidney	
Vanadium (b)	7440-62-2	67**	10000	980	NA	NA	9800	-Hair Loss	
Vernam	1929-77-7	51	510	0.1	0.2	0.2	1	-Body Weight	
Vinyl acetate	108-05-4	320	1700	0.4	3	3	4	-Kidney -Nasal	
Vinyl chloride (i)	75-01-4	0.2	0.8	0.007	0.02	0.02	0.07	-Liver	-yes
Xylenes, total	1330-20-7	130	700	0.2	3.9	3.9	2	-Neurological	
Zinc (b,c)	7440-66-6	26000	630000	***	NA	***	***	-Blood	
Zinc phosphide	1314-84-7	26	660	***	NA	NA	***	-Body Weight	
Zineb	12122-67-7	4100	82000	19	0.7	0.7	190	-Thyroid	

Soil Cleanup Target Levels

Contaminants	CAS#s	Direct Exposure: Residential (mg/kg)	Direct Exposure: Commercial/ Industrial (mg/kg)	Leachability Based on Groundwater Criteria (mg/kg)	Leachability Based on Freshwater Surface Water Criteria (mg/kg)	Leachability Based on Marine Surface Water Criteria (mg/kg)	Leachability Based on Groundwater of Low Yield/ Poor Quality (mg/kg)	Target Organs/Systems or Effects†	Carcinogen

Values expressed on a dry weight basis and rounded to two significant figures if >1 and to one significant figure if <1.

† = These default Target Organ(s)/Systems or Effects are those reported to occur at the doses used to derive the reference dose. Non-default Target Organ(s)/Systems or Effects may be justified through a detailed toxicological analysis of the chemicals present at a specific site.

* Contaminant is not a health concern for this exposure scenario.

** Direct exposure value based on acute toxicity considerations. This criterion is applicable in scenarios where children might be exposed to soils (e.g. residences, schools, playgrounds)

*** Leachability values may be derived using the SPLP Test to calculate site-specific SCTLs or may be determined using TCLP in the event oily wastes are present.

= Site concentrations for carcinogenic polycyclic aromatic hydrocarbons must be converted to Benzo(a)pyrene equivalents before comparison with the appropriate direct exposure SCTL for Benzo(a)pyrene using the approach described in the December 14, 2004 'Final Technical Report: Development of Cleanup Target Levels (CTLs) for Chapter 62-777, F.A.C.'

(a) = See discussion on the development of SCTLs for Ammonia in the December 14, 2004 'Final Technical Report: Development of Cleanup Target Levels (CTLs) for Chapter 62-777, F.A.C.'

(b) = Leachability values derived from USEPA Soil Screening Guidance (1996). These values were derived assuming soil pH 6.8. These leachability values are dependent upon both the metal concentration in soil and soil characteristics. Thus, if site-specific soil characteristics are different than the defaults, these leachability values may not apply. If this is the case, site-specific leachability values should be derived using methods such as TCLP or SPLP.

(c) = Phytotoxicity must be considered.

(d) = Residential direct exposure value from USEPA Revised Interm Soil Guidance for CERCLA Sites and RCRA Corrective Action Facilities. OSWER Directive 9355.4-12 (1994). The industrial direct exposure value was derived using methodologies outlined in USEPA 'Recommendations of the Technical Review Workgroup for Lead for an Interim Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil', December 1996; and in 'Blood Lead Concentrations of U.S. Adult Females: Summary Statistics from Phases 1 and 2 of the NHANES III', March 2002..

(e) = The SCTL for Dioxins, as total 2,3,7,8-TCDD equivalents should be compared to the total dioxin equivalents for chlorinated dioxin and dibenzofuran congeners using the approach described in the December 14, 2004 'Final Technical Report: Development of Cleanup Target Levels (CTLs) for Chapter 62-777, F.A.C.'

(f) = The common name BHC is a misnomer for hexachlorocyclohexane.

(g) = Unless concentrations for both chromium III and VI are known, total chromium concentrations should by compared with direct exposure SCTLs for chromium VI.

(h) = Residential chronic SCTL for cadmium should be used as a not-to-exceed value because the residential chronic SCTL for cadmium is indistinguishable from the SCTL based on acute toxicity.

(i) = Residential chronic SCTL for vinyl chloride calculated by adding prorated and non-prorated risks, as discussed in the December 14, 2004 'Final Technical Report: Development of Cleanup Target Levels (CTLs) for Chapter 62-777, F.A.C.'

Note: If more than one contaminant is present at a site, the direct exposure values are to be modified, if necessary, such that the sum of the hazard quotients for non-carcinogenic contaminants affecting the same organ(s) is 1 or less. For carcinogens, the direct exposure values shall be modified such that the cumulative lifetime risk level posed by the contaminants is 1.0E-06, as presented in Appendix D 'Draft Technical Report: Development of Cleanup Target Levels (CTLs) for Chapter 62-777, F.A.C.'

None Specified = Target organ(s) not determined at time of rule adoption.

APPENDIX IV - Sequential Batch Extraction Results for Waste Glass

									Total Metals (mg/L)													
Sample	Glass Color	Sorting	Days Extracted	BOD (mg/L)	COD (mg/L)	TOC (mg/L)	pH	Specific Conductivity	Antimony	Arsenic	Berryllium	Cadmium	Chromium	Cobalt	Copper	Lead	Mercury	Nickel	Selenium	Silver	Thallium	Zinc
AZ-1A	Brown	Dropbox /	1	4.9	29	4.9	10.3	59	ND	ND	ND	ND	ND	ND	0.11	0.002	ND	0.025	ND	ND	ND	0.037
		Barrel-	2	ND	11	1.5	10.1	23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.047
		Unattended	3	ND	ND	1.0	10.1	16	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND	ND	0.032
			4	ND	ND	1.0	10.0	18	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND	ND	0.026
			5	ND	ND	1.3	9.9	14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.037
			6	ND	ND	1.0	9.9	17	ND	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND	ND	0.096
			7	ND	ND	0.9	9.8	18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.026
			8	ND	ND	ND	9.7	19	ND	ND	ND	ND	ND	ND	ND	0.004	ND	0.021	ND	ND	ND	0.048
			9	ND	ND	ND	9.7	21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.022
			10	ND	ND	0.6	9.6	23	ND	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND	ND	0.032
AZ-1B	Brown	Dropbox /	1	6.4	32	5.9	10.1	42	ND	ND	ND	ND	0.024	ND	0.14	ND	ND	0.021	0.003	ND	ND	0.031
		Barrel-	2	ND	15	ND	10.0	23	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.027
		Unattended	3	ND	ND	0.7	10.0	20	ND	ND	ND	ND	ND	ND	ND	0.004	ND	ND	ND	ND	ND	0.022
			4	ND	ND	1.2	9.9	25	ND	ND	ND	ND	ND	ND	ND	0.003	ND	0.024	ND	ND	ND	0.050
			5	ND	ND	1.2	9.9	26	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND	ND	0.031
			6	ND	ND	ND	9.8	24	ND	ND	ND	ND	ND	ND	ND	0.004	ND	ND	ND	ND	ND	0.035
			7	ND	ND	1.0	9.7	26	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.028
			8	ND	ND	0.9	9.7	28	ND	ND	ND	ND	ND	ND	ND	0.003	ND	0.029	ND	ND	ND	0.025
			9	ND	ND	1.7	9.7	26	ND	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND	ND	0.035
			10	ND	ND	0.7	9.6	25	ND	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND	ND	0.025
WA-10	Mixed	Curbside -	1	ND	18	3.2	10.0	42	ND	ND	ND	ND	ND	ND	0.049	0.002	ND	ND	ND	ND	ND	0.023
		Commingled	2	ND	ND	1.0	10.0	23	ND	ND	ND	ND	ND	ND	ND	0.005	ND	ND	ND	ND	ND	0.054
		with other	3	ND	ND	2.0	10.0	20	ND	ND	ND	ND	ND	ND	ND	0.003	ND	ND	ND	ND	ND	0.025
		(plastics,	4	ND	ND	1.4	10.0	25	ND	ND	ND	ND	ND	ND	ND	0.007	ND	ND	ND	ND	ND	0.033
		cans) -	5	ND	ND	1.4	9.9	26	ND	ND	ND	ND	ND	ND	ND	0.004	ND	0	ND	ND	ND	0.032
		Negative	6	ND	ND	0.8	10.1	24	ND	ND	ND	ND	ND	ND	ND	0.003	ND	0.021	ND	ND	ND	0.033
		Sorting	7	ND	ND	1.6	9.9	26	ND	ND	ND	ND	ND	ND	ND	0.004	ND	ND	ND	ND	ND	0.020
			8	ND	ND	0.7	9.8	28	ND	ND	ND	ND	ND	ND	ND	0.004	ND	0.036	ND	ND	ND	0.028
			9	ND	ND	1.4	9.9	26	ND	ND	ND	ND	ND	ND	ND	0.005	ND	ND	ND	ND	ND	0.026
			10	ND	ND	1.2	9.9	25	ND	ND	ND	ND	ND	ND	ND	0.004	ND	ND	ND	ND	ND	0.024

Data from Cosentino et al. (1995)