



LEACHING CHARACTERISTICS OF ASPHALT ROAD WASTE

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Timothy G. Townsend
University Of Florida

State University System of Florida
FLORIDA CENTER
FOR SOLID AND HAZARDOUS WASTE MANAGEMENT
2207 NW 13 Street, Suite D
Gainesville, FL 32609

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Leaching Characteristics of Asphalt Road Waste

Timothy G. Townsend, Principal Investigator
Allan Brantley, Graduate Research Assistant
Department of Environmental Engineering Sciences
University of Florida
Gainesville, FL 32611-6450
(352) 392-0846

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LIST OF ACRONYMS AND UNITS OF MEASUREMENT

BDL	Below Detection Limit
COD	Chemical Oxidation Demand
DI	Deionized Water
EPA	Environmental Protection Agency
FDEP	Florida Department of Transportation
FDOT	Florida Department of Transportation
FL/AA	Flame Atomic Absorption
GC/MS	Gas Chromatography/Mass Spectrophotometry
GF/AA	Graphite Furnace Atomic Absorption
HMA	Hot Mix Asphalt
ITD	Ion Trap Detector
mg/L	milligrams per liter
NPOC	Non-Purgeable Organic Carbon
PAH	Polycyclic Aromatic Hydrocarbons
RCRA	Resource Conservation Recovery Act
SPLP	Synthetic Precipitation Leaching Procedure
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
µg/L	micrograms per liter
VOC	Volatile Organic Compounds

KEYWORDS

Asphalt

Leachate

Reclaimed Asphalt Pavement (RAP)

Polycyclic Aromatic Hydrocarbons (PAHs)

Leaching Columns

Synthetic Precipitation Leaching Procedure (SPLP)

Toxicity Characteristic Leaching Procedure (TCLP)

Batch Test

ABSTRACT

The construction and expansion of asphalt roadways result in the production of a large amount of asphalt road waste also known as reclaimed asphalt pavement (RAP). A major fraction of this RAP is recycled by incorporation into a new asphalt mixture. However, some of this material may remain as a solid waste and require disposal or reuse in some other form. One proposed alternative for the management of RAP is in the use as fill material, in applications such as embankments or construction fill. One limitation to using RAP as fill material stems from the unknown risks of pollutants leaching from the waste to the environment.

Data regarding the composition of leachate from RAP is limited. It has been suggested that chemical compounds such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals might be present in RAP and therefore leach from RAP. This might occur as a result of the chemical composition of asphalt and from contamination occurring from vehicle traffic on the roadway. An investigation was performed to address concerns associated with leaching of chemicals from RAP under simulated environmental conditions. Such an investigation also provides valuable information regarding possible environmental impacts associated with leaching of pollutants from large stockpiles of RAP.

A series of leaching tests were performed at both batch-scale and in leaching columns. This study focused on leachable pollutants and did not attempt to characterize the total concentration of pollutants in the RAP. The primary chemicals investigated were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. The results of the TCLP tests performed indicated that the RAP tested was not a hazardous waste. None of the compounds analyzed for were detected in the SPLP leachate. Based on existing waste management policy in Florida, the SPLP results indicated that RAP of the nature tested in this study would result in exceedances of groundwater guidance concentrations for the pollutants studied. In the column study, lead was detected in amounts slightly above the groundwater guidance concentration but decreased over time. One unsaturated column and three saturated columns (two sites) exceeded the 15 ppb groundwater guidance concentration. All but one column dropped to below 1 ppb by the end of the study.

The differences in lead concentrations observed in the batch study and column study were a result of the much greater solid-to-liquid ratio in the columns. It is standard practice to apply a dilution factor to actual leachate concentrations such as those from column tests (dilution is assumed to already occur in batch tests). Using typical dilution factors for land-applied waste, even the greatest concentration of lead measured in the leachate would be lower than the groundwater guidance concentration. Lead was observed at the greatest concentrations in the oldest RAP samples. This indicated that the lead was not a result of the aggregate or asphalt cement, but rather a result of vehicle traffic and emissions. The results of this research project indicated that RAP of the nature examined in this study poses minimal risk to groundwater as a result of pollutant leaching under normal land disposal or beneficial reuse scenarios. Conditions of possible concern would be RAP used in saturated environments where little dilution occurred.

EXECUTIVE SUMMARY

OBJECTIVES

Approximately 2.5 million miles of paved roads currently exist in the United States (NAPA, 1997). Due to daily wear and tear, roadway expansion, and construction related activities, these roadways sometimes need to be removed or repaired. During reconstruction or removal of a road surface, reclaimed asphalt pavement (RAP) is commonly obtained by milling or removing the existing pavement. RAP is typically recycled back into new hot mix asphalt, but in some instances all of it can not be re-used. A proposed alternative for the management of RAP is use as fill material. One limitation to using RAP as fill material stems from a lack of knowledge regarding possible environmental impacts of RAP.

Two different types of environmental concerns relate to leaching of pollutants from RAP. The first is the leachate produced when rainfall infiltrates RAP stockpiles. These RAP stockpiles can range in size up to 2000 yd³. Concerns have been expressed that the leachate produced could potentially be contaminated with trace amounts of hazardous chemicals, namely organic compounds or heavy metals. These chemicals could be the result of accidental spills onto the roadway from vehicles or possibly due to the virgin material used to make asphalt. A second environmental concern is the use of RAP as fill material. RAP used as fill material could potentially leach off contaminants when rainfall infiltrates the waste (an unsaturated condition). In some instances the RAP may be proposed to be used as fill below the water table (a saturated condition). In both situations, the leachate produced could potentially be contaminated with trace amounts of hazardous chemicals, such as organic compounds and heavy metals.

This project was conducted to address some of the environmental concerns expressed by regulators and others related to the leaching of pollutants from asphalt road waste, primarily RAP. A series of leaching tests were performed at both batch-scale and in leaching columns. The primary chemicals investigated were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. While it is generally recognized that RAP does not present a great risk to human health or the environment, a better characterization of the amount and type of chemicals that leach in the environment helps provide a better means to correctly manage this material.

ORGANIZATION OF REPORT

This research report is organized as follows: Chapter one provides a brief overview of the issues surrounding RAP and its potential environmental impacts. Chapter two reviews the relevant literature pertaining to asphalt road waste and its impact on the environment. This chapter also gives a background of different asphalt materials. Chapter three presents the experimental methodology for the study. Chapter four presents and discusses the results of the leaching studies. The final chapter discusses the results and provides conclusions.

METHODOLOGY

In light of the environmental concerns about RAP, a project involving a series of leaching tests was performed at the University of Florida Solid and Hazardous Waste Laboratory. The first step included collection of six RAP samples throughout the state of Florida. After sample collection, the FDOT bituminous laboratory physically characterized the RAP samples. Then a series of leaching tests were performed on the RAP samples. The first tests were typical batch-leaching tests including the TCLP, SPLP, and DI leaching procedure. The second test was a column leaching test performed to simulate a more realistic environmental condition. Leachate samples obtained from the batch experiments and column experiments were analyzed for the same parameters. The primary chemicals investigated were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. The total concentrations of pollutants in the RAP were not measured.

RESULTS AND DISCUSSION

Batch tests were performed on all six RAP samples. In the leachate generated during the TCLP batch test, measurements of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals all were below detection limit (BDL) and below any applicable TCLP limits. The RAP samples evaluated were therefore not a hazardous waste. This result was expected, as the literature had demonstrated this.

Batch tests are also used by regulatory agencies to determine whether a waste presents a potential leaching threat to groundwater. Concentrations of pollutants from batch tests are usually compared directly to groundwater limits or guidance concentrations. TCLP test are sometimes used. The literature did present some TCLP results that were above applicable groundwater limits for some heavy metals (Kriech 1990, 1991, 1992). The TCLP test is a somewhat aggressive test that represents the conditions inside an anaerobic landfill. Less aggressive tests were therefore also conducted in this study (SPLP and deionized water). The SPLP is currently the method of choice for evaluating leaching from waste or contaminated soils in Florida when exposed to rainfall.

In all of the batch tests, measurements of VOCs, PAHs, and selected heavy metals (Ba, Ca, Cr, Cu, Pb, Ni, and Zn) all were below detection limit (BDL) and were below applicable regulatory groundwater guidance concentrations. This indicated that the RAP samples tested did not pose an undue risk (in regard to leaching of the pollutants tested) under current waste policy in Florida. No comparisons can be made regarding the effectiveness of each test to leach pollutants because no pollutants were measured.

Column (lysimeter) tests were then performed on the same six RAP samples. Column tests are not a prescribed test procedure by regulatory agencies. They were conducted in this case to investigate leachate production from RAP under more realistic environmental scenarios. Approximately 60 lbs of RAP material filled a three foot section of each column. Duplicate columns were subjected to saturated and unsaturated conditions. Column leachate samples were analyzed for the same parameters as the batch tests and continued for a total of 42 days. The columns did leach large concentrations of ions such as calcium, sodium, sulfate,

fluoride, and carbonate as a result of mineral leaching from the aggregate used in the asphalt pavement manufacture. All VOC and PAH analytical results were similar to the batch test -- no compounds were detected. Leachate concentrations for selected heavy metals (Ba, Ca, Cr, Cu, Ni, and Zn) were always below detection limits (BDL). An exception was lead (Pb), which was detected.

Only one unsaturated lysimeter resulted in a leachate with a lead concentration above the groundwater guidance concentration (15 ppb). Leachate from the unsaturated lysimeter containing the Jacksonville sample had a lead concentration of approximately 24 ppb twelve days into the sampling period. The concentration of lead decreased over time and then leveled off well below the regulatory guidance concentrations. In the saturated columns, all columns had detectable concentrations of lead ranging from 5 ppb to 38 ppb. Three out of the six lysimeters (two sites) were above the regulatory guideline. The lysimeters decreased over time to lead concentrations below the guidance concentration (and the detection limit) except the Jacksonville sample. The Jacksonville sample concentration decreased slightly but was still above the guidance concentration at approximately 18 ppb.

The batch tests were more dilute than the column tests. This condition helps to explain why lead concentrations were observed in the column study but not in the batch test. In a real world situation, rainfall would ultimately dilute leachate produced from a stockpile before it reached the groundwater table or a nearby receiving body of water. This phenomenon is commonly referred to as dilution-attenuation. Attenuation models, used to determine the concentration of a pollutant in the groundwater resulting from waste piles and landfills, commonly use a dilution factor of 20 in their models. This dilution factor is accounted for in the batch test by the 20 to 1 liquid to solid ratio. In the column study, somewhat no dilution is involved. If the concentrations produced from the column studies were used as part of a groundwater dilution model, results would likely be below any regulatory guideline.

Lead was observed in the greatest concentrations in the oldest RAP samples. This indicated that the lead was not a result of the aggregate or asphalt cement, but rather a result of vehicle traffic and emissions. Lead has been used for many years in leaded gasoline and in crankcase oil. Since vehicle accidents and accidental spills contribute to this contamination, there is a possibility that this contamination was site specific. Previous studies regarding asphalt road waste also found trace amounts of lead in some circumstances. Since lead was encountered in greater concentrations in older samples, the source of lead was likely prolonged exposure to vehicle traffic and emissions. Under most reuse circumstances, even if lead were encountered at levels of the highest concentration measured in this study, the concentrations in the environment would be below acceptable regulatory levels for drinking water. Possible exceptions would be older RAP placed below the water table in areas with little or no dilution.

Most of the previous studies regarding RAP leaching were consistent with the results found in this study. Organic compounds do not leach from typical RAP under the conditions tested. Heavy metals are sometimes encountered. The literature indicated the presence of chromium, lead, and barium. Only lead was detected in this study and was ascribed to prolonged exposure to traffic and vehicle emissions. The literature often referred to chromium resulting from slag used as aggregate. It should be noted that the aggregate used in the asphalt

samples collected for this study was assumed to be natural aggregate (e.g. limerock). If other materials -- especially waste materials such as slag, spent sandblast grit and ash -- are used as aggregate, the results gathered here may not be applicable. It should also be noted that fresh asphalt was not tested, nor were extremes in temperatures evaluated.

CHAPTER 1

INTRODUCTION

In 1870 Professor E.J. DeSmedt laid the first asphalt pavement in Newark, New Jersey. Ever since this time, roadways have undergone a continuous process of construction and reconstruction. Today, approximately 2.5 million miles of paved roads exist in the United States (Roberts et al., 1996). Of these roads, approximately 95% are paved with asphalt, typically in hot mix asphalt (HMA) form. Even though HMA is considered to be the most durable and longest lasting paving material on the market, there are times when the asphalt must be removed and repaired. Daily wear and tear, roadway expansion, and construction related activities are some of the major factors that necessitate roadway removal. During reconstruction or removal of a road surface, reclaimed asphalt pavement (RAP) is commonly obtained by milling or removing the existing pavement. For this study, reclaimed asphalt pavement (RAP) is defined as all asphalt road waste, large chunks or milled material, that has been size-reduced, making it reusable as part of a new asphalt mixture.

Reclaimed asphalt pavement has been successfully re-used and recycled for many years. It has been stated that, “the recycling of old pavements [RAP] into new pavements is the largest single recycling practice in the United States” (FWATWG, 1997). The recycling of RAP has resulted in many beneficial effects including saving landfill space, conserving natural resources, and reducing costs of new asphalt mixtures. RAP is typically recycled back into new hot mix asphalt, but in some instances all of it can not be re-used. Typically the unused material remains on-site for long periods of time until re-use options develop or until landfilled in a permitted construction and demolition (C&D) waste landfill, which tends to be costly. Regulations governing C&D landfills have recently undergone revision at the state and federal level, resulting in stricter operational and monitoring requirements (FAC, 1998), and thus an increase in waste disposal fees.

Other proposed uses for the unused RAP have included roadbase material to stabilize dirt roads, pothole/rut filler, and roadway shoulder material. A proposed alternative for the management of RAP is use as fill material, whether by disposal in asphalt-only monofills or in beneficial reuse applications. Some states have classified asphalt road waste as clean fill (NAPA, 1998).

The Florida Department of Environmental Protection may consider provisions to categorize some waste materials as clean debris, typically less costly option than traditional landfilling. The Florida Administrative Code (FAC) states that “clean debris used as a fill material is not solid waste, and such use does not require a solid waste permit under this rule” (FAC, 1998). The limitation to using RAP as clean debris or fill material stems from the lack of knowledge related to the environmental impacts of RAP. There have been some concerns over the potential problems related to the unknown risks of pollutants leaching from this material to the environment (Binkley, 1994).

There are two different types of environmental concerns related to leaching of pollutants from RAP. The first is the leachate produced when rainfall infiltrates the RAP stockpiles. These RAP stockpiles can range in size up to 2000 yd³. There are concerns that the leachate produced may be contaminated with trace amounts of hazardous chemicals, primarily organic compounds or heavy metals. These chemicals could be the result of spills onto the roadway from vehicles or possibly due to the virgin material used to make asphalt. The second environmental concern is the use of RAP as fill material, either in a beneficial reuse option or simply as monofill disposal. RAP used as fill material could potentially leach off contaminants when rainfall infiltrates the waste in an unsaturated condition. In some instances the RAP material could be placed below the water table in a saturated condition. In both situations, the leachate produced could potentially be contaminated with trace amounts of hazardous chemicals, namely organic compounds or heavy metals.

This project was conducted to address some of the environmental concerns expressed by regulators and others related to the leaching of pollutants from asphalt road waste, primarily RAP. The study focused on leachable pollutants and did not attempt to characterize the total concentration of pollutants present in the RAP. A series of leaching tests were performed at both batch-scale and in leaching columns. The primary chemicals investigated were volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals. While it is generally recognized that RAP does not present a great risk to human health or the environment, a better characterization of the amount and type of chemicals that leach in the environment will help provide a better means to correctly manage this material.

This report is organized into five chapters. Chapter two of this report presents a review of the relevant literature pertaining to asphalt road waste and its impact on the environment. Chapter three presents the experimental methodology for the study. Chapter four presents and discusses the results of the leaching studies. The results are discussed and conclusions are provided in the final chapter.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a general background about asphalt and discusses existing literature related to reclaimed asphalt pavement (RAP) and its environmental impact. The first section provides a description of asphalt. The next section describes how asphalt concrete is manufactured and how roads are constructed. The third section gives an overview of asphalt concrete removal and recycling. The fourth section discusses alternate uses for asphalt. The fifth section discusses potential environmental impacts of RAP. The final section reviews existing studies related to asphalt, typically RAP.

2.2 DESCRIPTION OF ASPHALT

Asphalt is a natural component of nearly all types of petroleum found in nature (Asphalt Institute, 1989). By refining crude petroleum, various components can be separated and recovered, including asphalt. Asphalt has physical and chemical properties that make it of great interest to many engineers. It is a strong cement, extremely durable, readily adhesive, highly waterproof, and considered to be chemically inert. Asphalt is highly resistant to the reaction of many acids, alkalis, and salts. Asphalt is a viscoelastic substance that imparts both controllable elasticity and viscous flow to mixtures of aggregates with which it is commonly combined. Asphalt for pavement construction is called asphalt cement.

Asphalt cement is often added to aggregate to make asphalt concrete for construction of asphalt pavements for highways and parking lots. When these asphalt pavements are removed from a road surface, the by-product is commonly called reclaimed asphalt pavement (RAP). RAP consists of ground up asphalt pavement. For this study, RAP is defined as all asphalt road waste, large chunks or milled material, that has been size-reduced, making it reusable as part of a new asphalt mixture.

2.3 ASPHALT PRODUCTION AND ROADWAY CONSTRUCTION

Detailed descriptions of asphalt production and roadway construction have been presented elsewhere (NAPA, 1997), but a general overview is presented here. The most typical type of asphalt mixture produced is hot mix asphalt (HMA). HMA is generally a combination of 95% aggregate (rock, gravel, sand, or stone) and 5% asphalt cement. These percentages can change according to the specifications of the road being constructed. A typical site layout of a hot mix asphalt facility is shown in Figure 2.1.

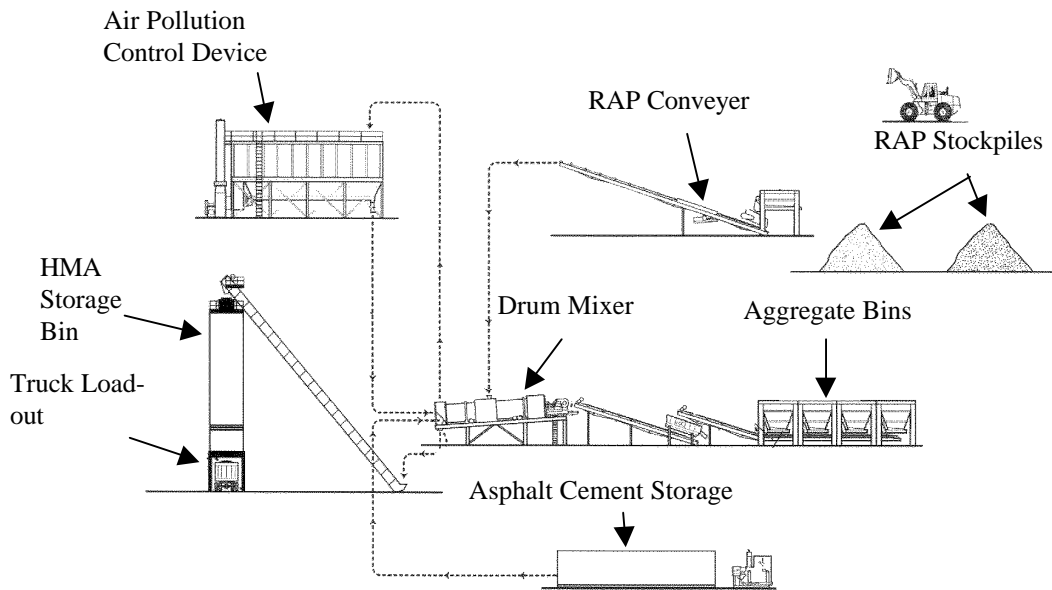


Figure 2.1 Typical Site Layout of a HMA Plant (Adapted from EPA, 1997)

Once the amounts of aggregate and asphalt cement are determined, the manufacturing of HMA is a rather simple process. The asphalt cement is heated and then mixed with the appropriate aggregate at a hot mix asphalt facility. Once the material is mixed, it is stored on site and then loaded into hauling trucks and transported to the paving site. When the truck reaches the site, it is a matter of minutes before the HMA is used. Waiting paving machines, with hoppers at the front end, are loaded with the HMA. The paving machine evenly spreads the asphalt mixture on the road while a vibratory roller follows behind and uniformly compacts the material. This entire process takes place in a matter of minutes. Since the temperature of HMA drops rapidly, it must be compacted to its specific density before the temperature drops below 175 degrees F. Once the road has been laid down and compacted, traffic is generally allowed to drive on the new asphalt.

2.4 ASPHALT REMOVAL AND RECYCLING

Hot mix asphalt is considered to be the one of the most durable and longest lasting paving materials on the market. As a result of daily wear and tear, roadway expansion, and construction related activities, there are times that roadways have to be rehabilitated or removed. This process is accomplished in two different ways. The typical method of choice for rehabilitation is the use of an excavation device known as a roadway milling machine or roadmiller.

A road miller has several hundred rotating steel/carbide teeth that scrape off a desired depth of the existing road surface. A typical road milling operation is shown in Figure 2.2. Depending on the type of machine and material in the pavement, asphalt road waste is produced with a maximum particle size of approximately $\frac{3}{4}$ to $\frac{1}{2}$ inches. The milled material is conveyed directly to an awaiting dump truck for transport back to the

asphalt plant and re-used in a new asphalt mixture. This milled material is what this report commonly refers to as reclaimed asphalt pavement (RAP).



Figure 2.2 Typical Roadway Excavation Process

If a project is small or a roadway area is inaccessible by a road miller, the road will be excavated with a front-end loader or backhoe. This process tends to produce large chunks of asphalt. According to this project’s definition of RAP, this material is not considered as reclaimed asphalt pavement until the large pieces are taken back to an asphalt plant and crushed into an appropriate size to be re-used in a new asphalt mixture.

2.4.1 Uses of Recycled RAP

One hundred percent of RAP is recyclable unless otherwise contaminated with debris. RAP is typically recycled back into new hot mix asphalt, but in some instances not all of it can be re-used. It has been estimated that approximately 90% of all RAP in the state of Florida is recycled back into new asphalt mixtures (Musselman, 1998). The procedure for recycling RAP into a new asphalt concrete mixture is simple. Once the road surface is milled, the RAP is transported back to the asphalt facility and re-crushed to a specific size needed for the new mixture’s specifications. RAP may make up to 25% by weight of the total asphalt mixture. It is mixed with additional virgin aggregate and heated asphalt cement. The mixture is re-mixed and ready to be placed down as a new road (NAPA, 1997).

During the Strategic Highway Research Program (SHRP) in 1992, a new method of mix design came about. This new mix design is known as “Superpave” (Superior PERforming Asphalt PAVements). Superpave was developed to produce asphalt

pavements that could withstand temperature extremes and increased traffic loads. Material selection was very important with “Superpave” mixes. As a result, the amount of RAP allotted for recycling back into a new asphalt mixture decreased (FHWA, 1997). This change in RAP allocation was small, but this in turn decreased the amount of RAP material recycled at any given time. This has caused the size of RAP stockpiles to increase, but for the most part the unused RAP is recycled back into new mixtures at later times.

Other uses for the unused RAP have included the following: roadbase material for stabilizing dirt roads, pothole/rut filler, and roadway shoulder material. A proposed alternative for the management of RAP is use as fill material, whether by disposal in asphalt-only monofills or in beneficial reuse applications as clean fill. According to the National Asphalt Pavement Association (1998) “many states have tested discarded asphalt pavement and determined that it should be categorized as clean fill.” The characteristics of a material that determines its status as clean fill are discussed in a future section.

2.4.2 Recycling Benefits

Recycling of RAP has both environmental and economical benefits. Environmentally, recycling of RAP saves natural resources and landfill space. Economically, recycling of RAP saves the asphalt facility owner money. In comparison to the use of virgin material, a cost saving of 25% can be achieved when RAP is recycled. It is not only the aggregate that saves the money, but the amount of asphalt cement obtained from the RAP. If RAP is not recycled, it must be disposed of in a construction and demolition (C&D) landfill which requires hauling costs and tipping fees. In 1994, it was estimated that recycling of RAP saved taxpayers in the U.S. over \$300 million a year (NAPA, 1997).

2.5 OTHER USES FOR ASPHALT

The common use for asphalt has been in asphalt concrete mixtures but there are several different applications in which asphalt has been used. Asphalt paving mixtures have been used to line fish hatcheries and industrial retention ponds. They have also been used as liners for water reservoirs. Asphalt cement has been used to line potable water lines and also to make shingles. Other uses for asphalt have been as a landfill liner and landfill cap. Detailed descriptions of alternate uses of asphalt have been presented elsewhere (NAPA, 1998).

2.6 POTENTIAL ENVIRONMENTAL IMPACTS OF RAP

In the past, there have been some environmental concerns regarding asphalt cement plants. These concerns dealt with the emissions produced at the plant, mainly gaseous and aerosol organic compounds and combustion products (EPA, 1997). The management and disposal of RAP has recently raised other environmental concerns.

A study performed in 1994 by Dr. Robert Livingston from Florida State University has resulted in some of these environmental concerns. Dr. Livingston performed studies

on lake sediments near asphalt roads and highways in Leon County. He tested for polycyclic aromatic hydrocarbons (PAHs), a compound commonly found in vehicle exhaust, lubricating oils, gasoline, and asphalt. Dr. Livingston found elevated concentrations of these PAHs in several of the lake sediment samples collected. His results suggested that this contamination was due to pollution runoff. Heavy roadway traffic caused the asphalt pavement to loosen and then the elevated temperatures of Florida caused these PAHs to “boil out” of the asphalt (Livingston and McGlynn, 1994).

From this study, an article was published in the Wall Street Journal, Florida Journal titled “Heat, Rain Draw Asphalt Poisons Into Florida’s Lakes, Study Shows” (Binkley, 1994). It was stated in this article that “Florida’s hot, wet climate aids the release of cancer-causing toxins from asphalt into the environment.” As a result of this study and the ensuing article, the number of people with environmental concerns related to asphalt materials, including RAP, increased.

There are two different types of environmental concerns related specifically to the leaching of pollutants from RAP. The first is the leachate produced when rainfall infiltrates RAP stockpiles. The major concern is that the leachate produced could potentially be contaminated with trace amounts of hazardous chemicals. The second environmental concern is the use of RAP material as fill material, either in a beneficial reuse scenario or in a monofill disposal situation. RAP used as fill material could potentially leach off contaminants when rainfall infiltrates the waste in an unsaturated condition. In some instances the RAP material could be placed below the water table in a saturated condition. In both situations, the leachate produced could potentially be contaminated with trace amounts of hazardous chemicals, namely organic compounds or heavy metals.

The major chemicals raised as a concern are Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals. “It has long been recognized that motor vehicles are an important source of metals and other contaminants [PAHs] to the environment” (Hewitt and Rashed, 1991). These hazardous chemicals may be the result of accidental spills onto the roadway from vehicles or possibly due to the virgin material used to make the RAP. Asphalt cement is a petroleum-derived material, and thus is composed of organic chemicals. Most volatile organic compounds and other semi-volatile compounds are not likely to be a major concern because they tend to evaporate over time when spilled on the roadway, or they are not likely to be present at all.

2.6.1 Description of Heavy Metals

Heavy metals are often cited as a concern when dealing with materials from roadways. Vehicle wear, fuel emissions, and fuel leakage could all result in contamination with heavy metals. In the case of lead (Pb), it is well documented that vehicular emissions cause contamination of roadside soils (Harrison and Wilson, 1981). Lead could result from leaded gasoline spills or from crankcase drippings. Other metals such as barium and chromium could result from a lubrication additive or from crankcase drippings. These heavy metals could remain on the roadway surface or be washed off in surface runoff.

Because of this heavy metal contamination, there is a concern that these heavy metals might be present in RAP. Table 2.1 presents a list of the TCLP (Toxicity Characteristic Leaching Procedure) metals under RCRA. These metals represent the more commonly evaluated heavy metals in regard to environmental contamination. The TCLP test will be discussed in a future chapter.

Table 2.1 TCLP Metals

Parameter
Barium
Cadmium
Chromium
Lead
Silver
Arsenic
Selenium
Mercury

2.6.2 Description of Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of chemicals formed primarily during the incomplete burning of coal, oil and gas, or other organic substances. It has been reported that sources of PAHs have included vehicle exhaust, weathered material from asphalt roads, lubricating oils, gasoline, diesel fuel, and tire particles (Takada et al., 1990). PAHs are also present throughout the environment in the air, water, and soil. In the environment, one is exposed to PAH vapors or PAHs that are attached to dust and other particles in the air. There are more than 100 different PAH compounds. The EPA has characterized 16 PAHs as priority pollutants and these are listed in Table 2.2.

The U.S. Department of Health and Human Services has determined that many PAHs may be considered carcinogenic (ATSDR, 1990). Several of the PAHs have caused tumors in laboratory animals upon ingestion, when applied to skin, or when inhaled. Reports in humans have demonstrated that exposure to PAHs for long periods has been associated with cancer.

Since PAHs are among the highest molecular weight group of organic compounds and asphalt has a high molecular weight, there is a concern that these compounds may be present in RAP. While it is generally recognized that RAP materials do not present a great risk to human health or the environment, a better characterization of the amount and type of chemicals that leach in the environment will help provide a better means to correctly manage this material.

Table 2.2 Polycyclic Aromatic Hydrocarbons (PAHs)

Parameter
Naphthalene
Acenaphthylene
Acenaphthene
Fluorine
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benz(A)Anthracene
Chrysene
Benzo(B)Fluoranthene
Benzo(K)Fluoranthene
Benzo(A)Pyrene
Dibenzo(A,H)Anthracene
Benzo(G,H,I)Perylene
Indeno(1,2,3-CD)Pyrene

2.6.3 RAP Used as Clean Fill

A proposed alternative for the management of RAP is use as fill material, whether by disposal in asphalt-only monofills or beneficial reuse. The state of Florida states that “clean [fill] may be used as fill material in any area, including waters of the State” (F.A.C., 1997). Clean fill is defined as “any solid waste which is virtually inert, which is not a pollution threat to ground water or surface waters, is not a fire hazard, and is likely to retain its physical and chemical structure under expected conditions of disposal or use” (F.A.C., 1997). Many states have already determined that asphalt road waste should be classified as clean fill (NAPA, 1998).

The determination of whether something is "clean" can be a difficult process. It depends on the intended disposition of the material, the possible pathways of risk, and appropriate environmental agency's regulations and policies. This issue is an ongoing and evolving process. In most cases, two major pathways of risk are considered. The first is direct exposure to humans through inhalation, ingestion, or dermal contact. The second is leaching to groundwater. In some cases, the risk to ecosystems may be considered.

The study reported here focused on the leaching risk resulting from RAP. Direct exposure was not addressed. There were a number of reasons for this. First, the issue of leaching has been the primary concern expressed in the literature and was the issue solicited in the request for proposals for this research project. Second, RAP management practices where direct exposure would be a great concern are few. RAP stockpiles at HMA facilities are restricted, and concern of direct exposure at these facilities by workers is much more likely to be targeted toward air emissions from HMA operation. RAP would not tend to be used as fill material in the same nature as soil, which most of the direct exposure limits or guidelines are developed for. It is not a material with soil-like

characteristics amenable to a human child digging or playing in. Most RAP particle sizes are much larger than soil. In construction, RAP would typically be used as structural fill below a layer of topsoil or other dirt. The scenario where RAP would be most likely in contact with humans is where the material was used as a surface material for a road, driveway or parking lot. It should be noted that this practice is already common in Florida.

Another issue complicating the analysis of RAP for the total concentration of pollutants is the fact that asphalt cement is an organic chemical. Typical environmental analyses for organic pollutants in solid waste or contaminated soil utilize an organic solvent to extract the pollutant from the waste or soil particles. Such organic solvents would simply dissolve the asphalt cement and its great variety of organic compounds. Asphalt is an organic, petroleum-derived material.

This study therefore addresses leaching concerns. If a scenario existed where direct exposure was a concern, different testing may be required by the regulatory agency. Under most current waste management policies, the evaluation of leaching risk is performed by determining the concentration of a pollutant that would occur in the groundwater after leaching from a waste, and comparing that concentration to the applicable groundwater guidance concentration. This can be done in a number of ways. The theoretical leachate concentration resulting from a total concentration present in the waste may be calculated, and a dilution factor applied. This was the process used to develop the soil clean up target levels for leaching currently used by Florida. A batch test such as TCLP or SPLP may be used to create a leachate, and the concentrations of pollutants in the leachate can be measured. A dilution factor is *not* applied in this case because dilution already occurs in the test. Finally, actual leachate can be produced using a test cell or a leaching column and applying an appropriate dilution factor.

As will be described in the following chapter, both batch leaching tests (TCLP and SPLP) and column tests were conducted on the RAP samples evaluated here.

2.7 LEACHING STUDIES

This section reviews existing literature regarding leaching from asphalt and reclaimed asphalt pavement (RAP). Two main types of studies were encountered in the literature. The first was the typical TCLP leaching test performed on different types of

asphalt material. The TCLP test is a batch leaching prescribed by the EPA to determine whether a solid waste is hazardous by toxicity characteristic and will be discussed in a future chapter. The second type were field studies performed to test leachate contamination from stockpiled asphalt materials.

The first experiment discussed is a TCLP leaching test performed on a new hot asphalt mixture. The next project discussed is a TCLP leaching test performed on six RAP samples. The third study discussed is a TCLP leaching test performed on Portland cement concrete and hot mix asphalt core samples taken from the same section of a road. The fourth investigation discussed is a field leaching test performed on a RAP stockpile. The final study discussed is a laboratory investigation conducted on slabs of asphalt pavement to simulate the release of hydrocarbons from the surface of asphalt pavements during a rainstorm.

2.7.1 Evaluation of Hot Mix Asphalt for Leachability

The purpose of this research was to determine what materials, if any, could leach from a new asphalt mixture (Kriech, 1990). This helped to evaluate whether or not the virgin material was initially contaminated and was also used as a control sample to test other RAP materials.

A #11 asphalt surface mixture was prepared and then tested for TCLP (Toxic Characteristic Leachability Procedure) by EPA method SW846-1311. The leachate produced from the TCLP testing procedures was then tested for the following: metals, VOCs, and Semi-VOCs, including PAHs.

The metals tested for were those heavy metals commonly tested by the EPA. All results were BDL (Below Detection Limit) except that of chromium. The results are summarized in Table 2.3. Chromium was measured at 0.1 mg/l. This was 50 times below the level considered hazardous by characteristic under RCRA (Resource Conservation Recovery Act). Since asphalt does not normally contain chromium compounds, it was ascertained that the chromium came from the slag material used as aggregate. The slag was a by-product of steel making. Slag and other waste materials are sometimes used as aggregate in some parts of the U.S..

Table 2.3 TCLP Metals

Parameter	Result (mg/L)	Detection limit (mg/L)
Barium	BDL	2.00
Cadmium	BDL	.020
Chromium	0.10	.010
Lead	BDL	.200
Silver	BDL	.040
Arsenic	BDL	.005
Selenium	BDL	.005
Mercury	BDL	.005

Using the TCLP zero head space extraction (ZHE) method, VOCs were tested for and all results were BDL. Semivolatile organic compounds were also tested for and results were BDL. PAHs are also a part of the semivolatile organic compounds, but are a concern of their own. All PAHs tested for were BDL except that of naphthalene. Naphthalene was detected at 0.25 µg/L but was still well below the regulatory guideline of 7.5 µg/L. Table 2.4 lists the PAH compounds of interest and results.

Table 2.4 Polycyclic Aromatic Hydrocarbons (PAHs)

Parameter	Result, (µg/L)	Detection limit (µg/L)
Naphthalene	.25	.096
Acenaphthylene	BDL	.150
Acenaphthene	BDL	.194
Fluorine	BDL	.023
Phenanthrene	BDL	.033
Anthracene	BDL	.015
Fluoranthene	BDL	.037
Pyrene	BDL	.040
Benz(A)Anthracene	BDL	.048
Chrysene	BDL	.017
Benzo(B)Fluoranthene	BDL	.020
Benzo(K)Fluoranthene	BDL	.022
Benzo(A)Pyrene	BDL	.023
Dibenzo(A,H)Anthracene	BDL	.018
Benzo(G,H,I)Perylene	BDL	.036
Indeno(1,2,3-CD)Pyrene	BDL	.021

Based on this study, it was concluded that the new #11 asphalt mixture produced very low levels of leachable compounds under TCLP conditions. All levels were well below any guidelines and regulatory standards.

2.7.2 Evaluation of RAP for use as a Clean Fill

The Heritage Research Group was contracted by the Illinois Asphalt Pavement Association (IAPA) to evaluate six RAP samples for their potential use as a clean fill material (Kriech, 1991). IAPA discussed that in certain situations, RAP is unsuitable for recycling back into a new asphalt mixture and could be used on-site for clean fill. The purpose of this study was to determine if RAP contained materials making it environmentally unsuitable for use as clean fill.

Six RAP samples were taken from different locations throughout the state of Illinois. These samples were analyzed in two parts. Physical tests were performed on each sample that included asphalt content, gradation, and Abson Recovery (physical properties of the recovered asphalt cement). The environmental testing consisted of Toxicity Characteristic Leaching Procedure (TCLP) for each RAP sample and a Polychlorinated Biphenyls (PCBs) test on the RAP samples prior to leaching. The

leachate produced from the TCLP testing procedure was then analyzed for the following constituents: metals, VOCs, and PAHs.

The metals tested for were those heavy metals commonly tested by the EPA under RCRA and can be found in Table 2.5. Results were BDL (Below Detection Limit) except for three samples (2,3,4). These results are summarized in Table 2.5. Barium was present in all three samples but was 200 to 300 times below the maximum concentration of contamination for TCLP under RCRA (100 mg/L). Barium was also below national drinking water standards (2 mg/L). Chromium and lead were also present in sample #2. They were both below the maximum concentration of contamination for TCLP under RCRA (5 mg/L and 5 mg/L respectively), but did not meet drinking water standards (0.1 mg/L and 0.015 mg/L respectively). Since sample #1 and sample #2 were both taken from the same project but at different sites, it was concluded that contamination possibly occurred on the surface from a vehicle. Lead contamination could have resulted from leaded gasoline or from crankcase oil. Chromium could have resulted from the wearing metal on vehicles or could have been in the slag aggregate (a by-product of steel making) used to make the asphalt.

Table 2.5 TCLP Metals

Parameter	Sample #1, (mg/L)	Sample #2, (mg/L)	Sample #3, (mg/L)	Sample #4, (mg/L)	Sample #5, (mg/L)	Sample #6, (mg/L)	Detection limit (mg/L)
Barium	BDL	.400	.360	.330	BDL	BDL	2.00
Cadmium	BDL	BDL	BDL	BDL	BDL	BDL	.020
Chromium	BDL	.520	BDL	BDL	BDL	BDL	.050
Lead	BDL	1.80	BDL	BDL	BDL	BDL	.200
Silver	BDL	BDL	BDL	BDL	BDL	BDL	.040
Arsenic	BDL	BDL	BDL	BDL	BDL	BDL	.005
Selenium	BDL	BDL	BDL	BDL	BDL	BDL	.005
Mercury	BDL	BDL	BDL	BDL	BDL	BDL	.005

Polychlorinated Biphenyls (PCBs) were tested for and all results were BDL. Semivolatile organic compounds were also tested for and all results were BDL. Polycyclic Aromatic Hydrocarbons are a part of the semivolatile organic compounds, but are a concern of their own. Table 2.6 lists the PAH compounds of interest and results.

Table 2.6 Polycyclic Aromatic Hydrocarbons (PAHs)

Parameter	Sample #1, (µg/L)	Sample #2, (µg/L)	Sample #3, (µg/L)	Sample #4, (µg/L)	Sample #5, (µg/L)	Sample #6, (µg/L)	Detection limit, (µg/L)
Naphthalene	.490	BDL	.490	.300	BDL	BDL	.130
Acenaphthylene	BDL	BDL	BDL	BDL	BDL	BDL	.200
Acenaphthene	.140	BDL	.140	BDL	BDL	BDL	.130
Fluorine	BDL	BDL	BDL	BDL	BDL	BDL	.015
Phenanthrene	BDL	BDL	BDL	BDL	BDL	BDL	.130
Anthracene	BDL	BDL	BDL	BDL	BDL	BDL	.017
Fluoranthene	BDL	BDL	BDL	BDL	BDL	BDL	.017
Pyrene	BDL	BDL	BDL	BDL	BDL	BDL	.060
Benz(A)Anthracene	BDL	BDL	BDL	BDL	.017	BDL	.017
Chrysene	BDL	BDL	BDL	BDL	BDL	BDL	.033
Benzo(B)Fluoranthene	BDL	BDL	BDL	BDL	BDL	BDL	.023
Benzo(K)Fluoranthene	BDL	BDL	BDL	BDL	.050	BDL	.017
Benzo(A)Pyrene	BDL	BDL	BDL	BDL	BDL	BDL	.240
Dibenzo(A,H) Anthracene	BDL	BDL	BDL	BDL	BDL	BDL	.068
Benzo(G,H,I)Perylene	BDL	BDL	BDL	BDL	BDL	BDL	.110
Indeno(1,2,3-CD) Pyrene	BDL	BDL	BDL	BDL	BDL	BDL	.022

Conclusions reached by the authors from this study were that all of the samples met current guidelines for maximum concentration of contamination for TCLP under RCRA. The migration of metals was greatly impaired by the matrix of the asphalt and aggregate. The contamination encountered could possibly have been spread by vehicles through fluid spills, accidents, and general wear and tear on a vehicle. The researchers concluded that reclaimed asphalt pavement (RAP) should give no concern if used as a clean fill material.

2.7.3 Leachability of Asphalt and Concrete Pavements

The purpose of this study was to determine if the use of concrete, asphalt, or soils from the surrounding roadway would be appropriate for use as a clean fill (Kriech, 1992). The major concern was that accidental spills onto the road surface from vehicles could contaminate the pavement and the surrounding road site. This possible contamination could make the material unsuitable for use in clean fill applications below the water table. The compounds of interest were the PAHs and heavy metals. These were chosen because volatile and semi-volatile compounds spilled onto the roadway would evaporate quickly.

The Illinois Department of Transportation (IDOT) located a segment of roadway that contained a Portland Cement concrete section joined by a hot mix asphalt (HMA) section. Both sections were built at the same time and traffic on each was identical. Three sites were randomly selected from each pavement and three 4-inch core samples were taken longitudinally from each. The first sample was taken between the wheel path of the vehicles, the second was in the outer wheel path, and the third was outside the outer wheel path. A soil sample was also taken of the shoulder roadway. Laboratory prepared

samples of Portland Cement concrete and hot mix asphalt were also tested. These samples had compositional mixtures considered typical by the IDOT and were used as control samples.

To test different hypothesis about pavement contamination, representative samples from each sample location were combined with other sample sites. The first hypothesis was that contamination would be greater between the wheel path due to crankcase drippings. Thus all samples taken between the wheel path were combined into one sample. The second hypothesis was that all samples taken from the wheel path would be cleaner due to the constant wear on the pavement. Thus all samples taken from the wheel path were combined into one sample. Samples outside the wheel path were also combined, as were the soil samples.

The samples were prepared and then tested for TCLP (Toxic Characteristic Leachability Procedure) by EPA method SW846-1311. The leachate produced from the TCLP testing procedure was then tested for selected metals and PAHs.

The laboratory prepared samples both had measurable amounts of metals, but no measurable amounts of PAHs. Small amounts of chromium (0.072 mg/L) were detected in the laboratory concrete sample and barium (2.9 mg/L) in the laboratory HMA sample. Two of the concrete samples had trace amounts of phenanthrene detected while four samples had trace amounts of naphthalene detected. Barium was detected at 1.2 mg/L in one of the concrete samples while the soil sample had a concentration of 3.5 mg/L.

The leachate results for the HMA samples appeared quite similar to the Portland Concrete cement leachate results. One of the HMA samples had trace amounts of phenanthrene detected while four samples had trace amounts of naphthalene detected. Barium was detected in three of the HMA samples as well as the control sample and soil sample.

The hypothesis that contamination would be greater between the wheel paths was not supported by the results. Overall the PAH concentrations were too low to determine any trends. Conclusions from this study were that all of the samples met current guidelines for maximum concentration of contamination for TCLP under RCRA. Both the Portland Concrete cement and HMA samples had relatively low concentrations of leachable metals and PAHs. The levels for both are quite similar to that of the soil samples and laboratory control samples.

2.7.4 An Investigation of Water Quality in Runoff from Stockpiles of Salvaged Concrete and Bituminous Paving

The purpose of this study was to determine the quality of runoff water from salvaged pavement stockpiles (Sadecki et al., 1996). The Minnesota Department of Transportation (MN/DOT) performed test on three stockpiles: coarse concrete material, fine concrete material and reclaimed asphalt pavement (RAP). Discussion will only be about the RAP stockpile.

A pile of RAP was placed on top of a plastic liner open to the environment. The liner was an impermeable barrier that allowed the leachate produced to be collected. Leachate was automatically collected by a catch basin and periodically collected and tested. The site layout is shown in Figure 2.3. The Minnesota Department of Health Laboratory, using US EPA approved methods, analyzed the leachate samples. Some physical tests were performed including: pH, conductivity, turbidity, total solids, total dissolved solids, and alkalinity. The leachate collected was also tested for metals and PAHs.

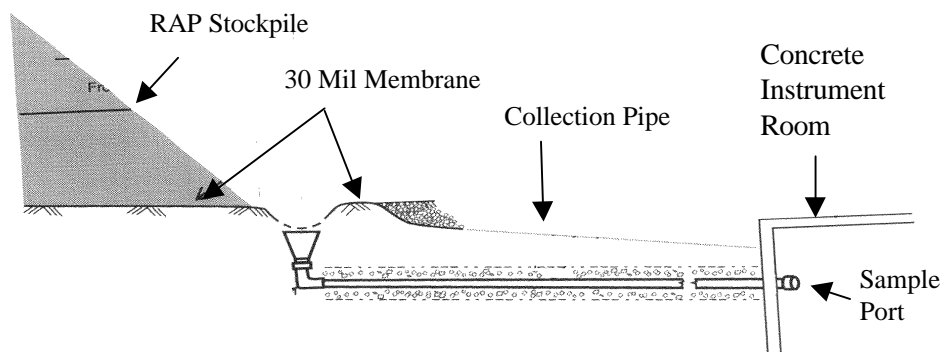


Figure 2.3 Site Layout of Experimental RAP Pile (Sadecki et al., 1996)

The primary concerns encountered in the leachate from the RAP material reduced to solids, pH, and chromium. In some instances, the dissolved solids were detected at levels higher than the secondary drinking water standards. The sediments washing from a pile could potentially cause erosion problems by forming deltas and reducing the depth of an aquatic habitat. The median pH value of the RAP material (8.1) exceeded the Minnesota standard of 8.0 for surface water quality suitable for fishing and recreation. Chromium also exceeded the standards for surface waters. It was concluded that chromium could have resulted from the wearing metal on vehicles or could have been in the slag aggregate (a by-product of steel making) used to make asphalt. PAHs are always a concern when dealing with RAP because of the possible carcinogenic effect it might have. PAH concentrations from the RAP material were nearly at or below detection limits.

The results of this study were used to assist the state, county, and city engineers in choosing storage sites for the stockpiles. It was concluded that careful planning for RAP stockpiles should include management practices of controlling runoff similar to those used for construction sites (berms, straw bales, grass or other filter channels, etc.). There could be possible impacts to the ground water system if stockpiles were located in areas sensitive to pollution. It was suggested that future studies are needed to assist in these problems.

2.7.5 The Geochemical Cycling of Hydrocarbons in Lake Jackson, Florida

The purpose of this study was to identify and quantify hydrocarbons in Lake Jackson (Byrne, 1980). As part of this study, a separate experiment was performed in the lab to simulate stormwater runoff from asphalt pavement. Discussion will only be about this laboratory experiment.

The investigation began by preparing four asphalt sheets (36 cm²). Two were used as control blanks and the other two had three milliliters of used crankcase oil added to each. The asphalt sheets were then allowed to dry for five days. They asphalt sheets were then rinsed with deionized water to simulate rainfall runoff conditions. Figure 2.4 illustrates the experimental setup. Tests were performed to simulate summer and winter-like conditions. Six samples were collected over a five-hour period and then analyzed for total dissolved petroleum hydrocarbons.

Results for this experiment are presented in Table 2.7. In the winter simulation sample, the initial runoff was higher than that of the control. It was ascertained that this might have indicated “oil bleed” into the initial runoff. All other sample times resulted in hydrocarbon concentration less than the control. In the summer simulation sample, five out of the six samples resulted in higher concentration than the control. It was concluded that there was a possibility of organics being leached from asphalt during an extended period of time. It was also suggested that an increase in temperature during summer months could also result in an increase in hydrocarbons released into stormwater runoff.

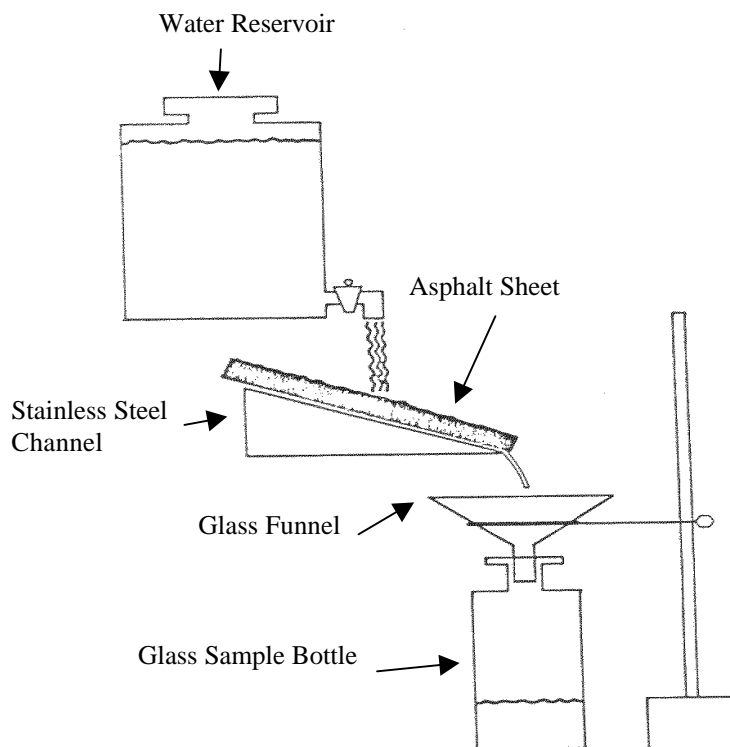


Figure 2.4 Experimental Setup (Byrne, 1980)

Table 2.7 Total Dissolved Petroleum Hydrocarbons

Time (hrs)	Winter Control (µg/l)	Winter Sample (µg/l)	Summer Control (µg/l)	Summer Sample (µg/l)
0	28	38	9	18
.5	16	11	4	10
1	16	11	29	13
2	35	23	6	7
3	13	10	2	9
5	35	13	6	10

2.7.6 Synopsis of Literature Studies

A few chemicals were observed to leach from asphalt road waste. The primary chemicals encountered were the heavy metals lead, chromium, and barium. The asphalt tested by TCLP was never found to be hazardous. Some concentrations in the TCLP leachate were greater than drinking water standards. The TCLP test is an aggressive test designed to simulate the interior of an anaerobic landfill. Other leaching tests are likely more suitable to measure actual leaching in non-landfilled environments.

CHAPTER 3

METHODOLOGY

The methodology for this project involved collecting reclaimed asphalt pavement (RAP) samples from different facilities around the state of Florida, physically characterizing the material, performing a series of leaching tests on the samples, and measuring the concentrations of various chemical constituents that leached off the material. Field sampling was performed according to FDEP standard operating procedures and laboratory analysis was conducted according to EPA and Standard Methods methodology. Field sampling and laboratory analysis methodologies are both outlined in the University of Florida Environmental Engineering Sciences Solid and Hazardous Waste Research Program’s Comprehensive Quality Assurance Plan (COMPQAP #960218).

3.1 SAMPLE SITES

The first task was to select six different RAP sources throughout the state of Florida. Emphasis was placed on collecting samples that could characterize the state as a whole. Four of the samples were collected from mixed source, crushed RAP stockpiles at hot mix asphalt plants. The crushed RAP piles were a combination of many different sources. The remaining two samples were collected from specific milling projects. Table 3.1 provides the sample location, sample date, and sample pile description. The sampling locations throughout the state are shown in Figure 3.1. This map shows that the farthest northwest sample collected came from I-10 in Suwannee County. No sample was collected from Northwest Florida because RAP was fairly scarce at the time of sampling. A RAP pile seemingly parallels population density—as population density increases, more construction activity occurs, thus generating more RAP piles (Warren, 1998). It should also be noted that the site-specific milled asphalt samples (I-10 and Indian Town Road) were not collected at the actual road site, but were collected from nearby hot mix asphalt plants where the RAP was hauled to.

Table 3.1 Sample Location, Sample Date, and Sample Pile Description

Facility/Sample Location	Date Sampled	Sample Pile Description
Miami	September 16, 1997	½” Crushed mixed source pile
Tampa	September 16, 1997	¾” Crushed mixed source pile
Jacksonville	October 2, 1997	¾” Crushed mixed source pile
Lake City	October 2, 1997	¾” Crushed mixed source pile
SR –8 (I-10)/ Suwannee County	October 2, 1997	½” Milled asphalt
Indian Town Road/ Palm Beach County	November 25, 1997	½” Milled asphalt

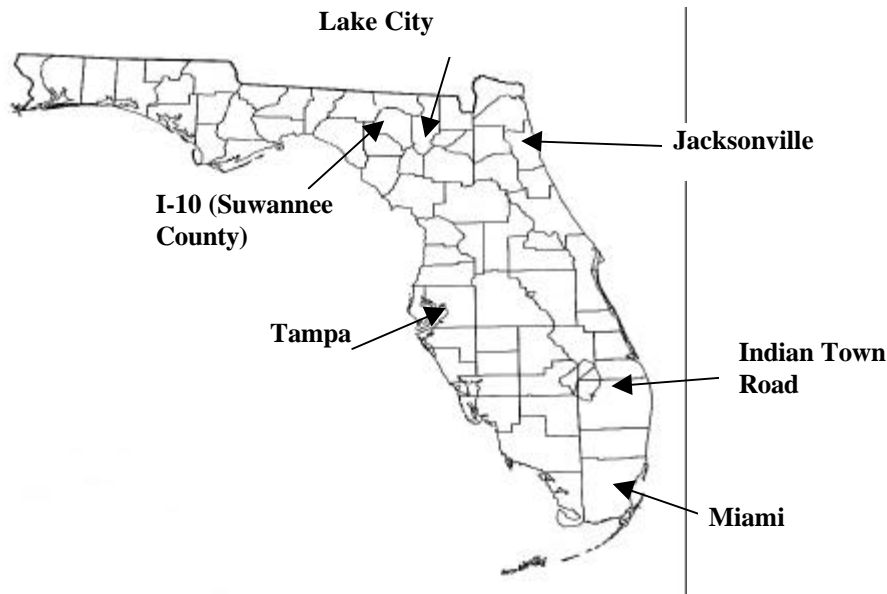


Figure 3.1 Sampling Locations throughout the State

3.2 SAMPLE COLLECTION

The main objective involved in collecting the RAP samples was to obtain a representative sample from a given source pile. All field sampling was performed according to FDEP standard operating procedures (FDEP, 1992). The field sampling methodology is outlined in the University of Florida Environmental Engineering Sciences Solid and Hazardous Waste Research Program’s Comprehensive Quality Assurance Plan (COMPQAP #960218).

The following sampling routine was employed at every sampling site. Eight specific subsamples were removed from the interior of the RAP pile with on-site equipment such as a front-end loader. The interior of the pile was used to avoid surface material that had been exposed to the environment for an extended period of time. This may often result in a “crusting” of the surface. The subsamples were then placed on the ground in one large pile and mixed thoroughly together. The pile was then leveled to approximately one foot in height, thus providing more surface area to sample from.

Samples were collected in order of sensitivity: volatile organic compounds (VOCs), semivolatile organic compounds (Semi-VOCs), metals, and then bulk samples. The sample containers and equipment included: two 1-liter glass jars with Teflon-lined lids, four cloth sampling bags (those commonly used by the FDOT), non-powdered latex gloves, stainless steel spoons, an insulated ice chest, and ice. All sampling equipment was pre-cleaned and decontaminated prior to the sampling trip. This process was performed at the University of Florida Solid and Hazardous Waste Lab.

Using gloves and a stainless steel spoon, approximately 25 RAP subsamples were taken from random spots in the pile and placed into the 1-liter glass jars for VOC analysis. The procedure was repeated for Semi-VOCs and metals analysis. The four cloth bags were then

filled with RAP samples from the same areas in which the 25 subsamples were taken. One bag was delivered to the FDOT State Materials Lab in Gainesville, Florida for physical characterization. The remaining three were collected for filling the leaching columns. All materials were stored in a cold room at 4 °C until analysis.

3.3 SAMPLE ANALYSIS

Sample analysis included physically characterizing the material, performing a series of leaching tests on the samples, and measuring the concentrations of various parameters that leached off the material. The leaching experiments included batch leaching as well as column leaching tests.

3.3.1 Physical Characterization

The RAP samples collected from each site were physically characterized at the FDOT State Materials Lab in Gainesville Florida by FDOT technicians. The analytical tests and testing methods are presented in Table 3.2.

Table 3.2 Analytical Tests and Methods for RAP Physical Characterization

Analytical Test	Method
Asphalt Content	Florida Methods FM-5-544, Quantitative Extraction of Bitumin from Bituminous Paving Mixtures by Use of a Non-chlorinated Solvent
Absolute Viscosity	Florida Methods FM-1-T202, Viscosities of Asphalt by Vacuum Capillary Viscometer
Gradation	Florida Methods F5-5-545, Mechanical Analysis of Aggregate Extracted by Use of a Non-chlorinated Solvent
Penetration	AASHTO 49-96, Penetration of Bituminous Material

An extraction procedure, which separated the asphalt cement from the aggregate, was the basis for determining the asphalt content (% asphalt) of the RAP samples. The purpose of the viscosity tests was to determine the flow characteristics of asphalt cement in a range of temperatures used during application. Gradation tests determined the relative particle size distribution of fine and coarse aggregates by use of a sieve analysis. The penetration test determined the relative hardness or consistency of the asphalt cement by measuring the distance that a standard needle penetrated vertically into the sample or asphalt under known conditions of temperature, loading, and time. These physical characterization tests were useful in assessing the condition and age of the milled asphalt samples.

3.3.2 Leaching Experiments

Two primary leaching methodologies were used: batch leaching and column leaching. The batch leaching tests consisted of three types: the toxicity characteristic leaching procedure (TCLP), the synthetic precipitation leaching procedure (SPLP), and a deionized water leaching procedure. The SPLP leaching solution was chosen for the column study because it was more

representative of Florida rainfall and was a preferred choice by regulators for determining impacts of non-landfilled waste on groundwater. Leachate samples obtained from the batch experiments and column experiments were both analyzed for the same parameters. The analytical testing methods for the leaching experiments are presented in Table 3.3.

TABLE 3.3 Analytical Tests and Methods for Leaching Experiments

Analytical Test	Method
Toxicity Characteristic Leaching Procedure (TCLP)	SW846-1311
Synthetic Precipitation Leaching Procedure (SPLP)	SW846-1312
Deionized Water Leaching Procedure	-
Column Leaching Procedure	-

The TCLP test is the assay prescribed by the EPA to determine whether a solid waste is hazardous by toxicity characteristic. A solid sample is size-reduced to a particle size below 9.5 mm and added to a leaching solution at a 20-to-1 liquid-to-solid ratio. The leaching solution is an acetic-acid based solution, with a pH dependent on the buffering capacity of the waste. The TCLP leaching solution was designed to simulate anaerobic conditions within a landfill. The mixture is agitated for 18 hours in a rotary extractor, and then the leachate is filtered, preserved, and stored according to the parameter of interest.

Although the TCLP test is primarily used to determine hazardous characteristics, it is sometimes used to determine the impact of a waste on groundwater even when the waste is stored or disposed in nonlandfill conditions. A more suitable test for this scenario is SPLP. The SPLP assay uses a leaching solution that simulates acid rain. It is a preferred choice by many regulators for determining impacts of waste on groundwater. Other than the leaching solution, all other aspects of the test remain the same. A third leaching test using deionized water was performed to examine the impact of a non-aggressive solution.

Two main differences were prominent between the batch test and column test: the liquid-to-solid ratio and the testing time. The batch test consisted of a 100-gram sample combined with 2 liters of leaching solution. This resulted in a 20-to-1 liquid-to-solid ratio. For the unsaturated column leaching test, the columns contained 60 lbs of RAP with the addition of 1 liter of leaching solution. This resulted in a 0.0367-to-1 liquid-to-solid ratio. For the saturated leaching test, the columns contained the same 60 lbs of asphalt sample but with the addition of 7 liters of leaching solution. This resulted in a 0.257-to-1 liquid-to-solid ratio. The batch test had less solid sample in contact with the leaching solution than either of the column test conditions.

The other prominent difference between the two tests was the time of contact between the RAP and the leaching solution. The batch study was a one-cycle test with a continuous contact time of 18-hours. For the unsaturated columns, 1 liter of leaching solution was added over a 20-minute interval and allowed to travel through the RAP material. The columns were drained and samples were collected every two days and then the process was repeated. The contact time between the leaching solution and RAP sample was the amount of time needed to travel through 3 feet of RAP material. In the saturated columns, seven liters of leaching

solution were added to the columns saturating the entire RAP sample. Since the columns were drained and samples taken every 14 days, the contact time between the leaching solution and the RAP material was 14 days. The two column scenarios allowed observation of simulated environmental conditions where RAP was either rained upon or saturated with water. It also allowed for observation of a possible “first-flush” scenario where leachate concentrations decrease over time. Comparisons of all testing parameters for the batch and column tests are presented in Table 3.4.

Table 3.4 Comparison of Testing Parameters for Batch and Column Test

	Batch	Column (Sat)	Column (Unsat)
Sample Mass	100 gram	60 lbs.	60 lbs.
Sample Size	< 9.5 mm	< ¾”	< ¾”
Leaching Solution Vol.	2 liters	7 liters	1 liter
Liquid:Solid Ratio	20:1	.257:1	.0367:1
Leaching Solution Contact Time	18 hrs	14 days	Unsaturated travel time through column
Samples Collected	1	Every 14 days	Every 2 days

3.3.3 Batch Experiments

The batch studies were conducted prior to the lysimeter experiment. The batch leaching tests consisted of the TCLP, SPLP, and DI leaching procedure. The procedure for all three tests was the same except for the addition of the appropriate leaching solution. The batch studies were performed on all six RAP samples with analysis of VOCs, PAHs, metals, and general water quality parameters.

To test for VOCs, a zero headspace method was used. Zero headspace extractors (ZHEs) were used to measure the leaching of volatile components of from the RAP samples. The procedure began by transferring the RAP sample collected for VOC analysis to a stainless steel bowl, and then size reducing the material to less than 9.5 mm. This was performed in a 4 °C cold room to minimize loss of VOCs. A 25-gram sample was then transferred to a stainless steel zero headspace extractor (ZHE). A 0.45µm glass-fiber filter, placed in between two stainless steel filters, was placed on top of the sample. The ZHE was sealed and a calibrated tool was used to force air out of the ZHE to achieve minimum headspace. Then, 500 ml of the appropriate leaching solution were added to the ZHE and then the vessel was rotated for 18(+/-2) hours. The ZHE method allowed for the VOCs present in the RAP sample (if any) to be leached to the liquid phase with minimal loss to the headspace (air phase). After rotation, samples were collected for VOC analysis using a glass syringe and then transferred to 40-ml glass vials. The samples were then analyzed on a GC/MS for VOCs of interest.

To test for PAHs and metals, a 2-liter extraction method was used. The procedure began by transferring the RAP sample collected for PAHs and metals analysis to a stainless steel bowl and then size reducing the material to less than 9.5 mm. This was performed in a 4 °C cold room to minimize loss of PAHs. A 100-gram sample was then transferred to a 2-liter glass jar. Two liters of the appropriate leaching solution were added and then the jar was sealed with Teflon tape and a Teflon lined lid. The sample container was rotated for 18(+/-2)

hours. Following rotation, the liquid extract was filtered through a stainless steel pressure filter rotation device containing a 0.45- μm glass fiber-filter. The filter device was pre-rinsed with nitric acid and analyte free water prior to sample filtration. Samples were collected for analysis of metals, PAHs, and general water quality parameters.

3.3.4 Column Leaching Experiments (Lysimeters)

Column leaching tests were performed to simulate more realistic environmental condition. There were two environmental conditions simulated with this column study. A saturated condition in which the asphalt was completely submerged with the SPLP leaching solution was observed. This type of test helps to simulate scenarios where RAP might be used as a fill below the water table. An unsaturated condition in which the SPLP leaching solution was added in doses was also observed. This type of test helped to simulate environmental conditions in which rainfall occurred in daily doses. As mentioned above, the SPLP leaching solution was chosen for the column study because it was more representative of Florida rainfall and was a preferred choice by many regulators. While batch conditions were easier to perform, the column tests allowed for determination of effects such as “first-flush” (Harrison and Wilson, 1985). This effect occurs when contaminants are leached off when first exposed to leaching solution but diminish in concentration over time.

The testing apparatus consisted of sixteen stainless steel leaching columns (also known as lysimeters). Eight of the columns were used for the saturated condition and the other eight were used for the unsaturated condition. The lysimeters were constructed of 6” diameter Type 316 stainless steel, Teflon O-Rings, and Type 316 S.S. filter screens. The entire column apparatus is shown in Figure 3.2. A diagram of a lysimeter is provided in Figure 3.3.

The SPLP leaching solution was pumped from a 16-gallon Type 316 S.S. reservoir, through a flow meter, and then to the individual flow meters and columns. The pump (FMI Lab Pump, Model QD-Q2) was constructed of Type 316 S.S., Teflon, ceramic, and had a maximum flow rate of 1242 ml/min. The flow meters were constructed of Teflon, Type 316 S.S., and glass. Samples were collected from the bottom port through a Type 316 S.S. valve and Teflon tube. It is important to note that the entire apparatus was constructed of Type 316 S.S., Teflon, glass, or ceramic material.

FDEP sampling protocols suggest using these types of material when sampling for the parameters of interest in this study. This was performed to ensure the integrity of the results. There is currently no standard methodology for a column study, but the procedure followed was felt to meet the needs of this study.



Figure 3.2 Column Leaching Apparatus

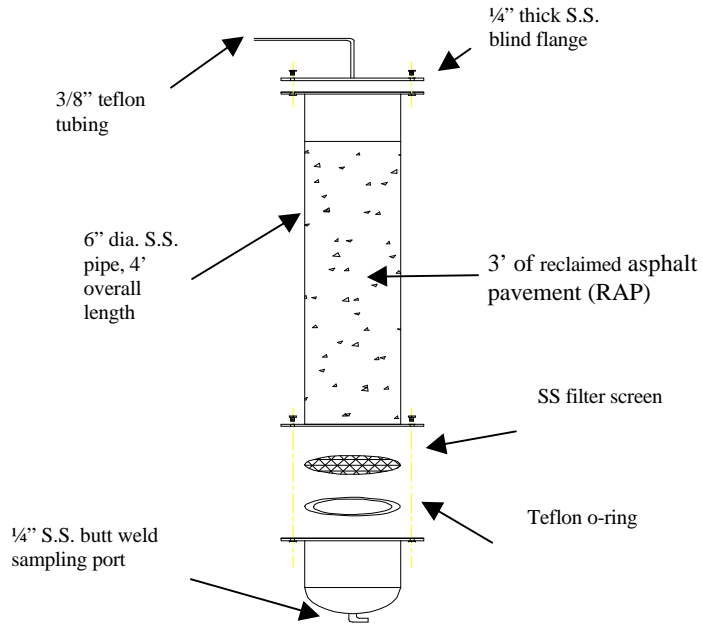


Figure 3.3 Typical Leaching Column (Lysimeter)

3.3.5 Sample Loading and Collection

Loading of the columns took place on December 14, 1997. The columns were pre-cleaned with deionized water and then rinsed with a dilute nitric acid solution. The columns were then rinsed again with deionized water and then pre-rinsed with SPLP leaching solution. The loading process began by placing a stainless steel filter screen at the bottom of the column. Approximately 6-inches of gravel was placed on top of the screen and then another stainless steel screen was placed on top of the gravel. The gravel and screen were cleaned, rinsed with nitric acid, and heated in an oven at 110 °C over night. The addition of the gravel allowed for the unsaturated leachate samples to remain separated from the RAP sample after draining to the bottom of the lysimeter. The stainless steel filter screen (#50) protected against infiltration of particles into the leachate samples.

The RAP samples were then loaded into the columns with approximately 3 feet of RAP material placed into each column. Three inches of fine sand were placed on top of the RAP to help distribute the leaching solution evenly through the column. The sand was pre-cleaned in the same manner as the gravel. It should be noted that a duplicate and control blank were also tested to ensure the integrity of the results. The RAP sample and corresponding lysimeter, sample mass, and bulk density are presented in Table 3.5.

Table 3.5 RAP Sample, Corresponding Lysimeter, and Sample Mass

Lysimeter #	RAP Sample	Sample Mass (lbs.)	Bulk Density (lb/ft³)
Lysimeter 1	Miami	61.07	103.68
Lysimeter 2	Lake City	66.64	113.13
Lysimeter 3	Indian Town Road	63.33	107.51
Lysimeter 4	I-10 (Suwannee County)	59.51	101.03
Lysimeter 5	Tampa	64.83	110.06
Lysimeter 6	Jacksonville	65.91	111.89
Lysimeter 7	Indian Town Road Duplicate	63.06	107.05
Lysimeter 8	Control Blank	-	-

As discussed earlier, the synthetic precipitation leaching procedure (SPLP) solution was the leaching solution used for the column experiments. The saturated columns were the first columns to be filled with this solution. The SPLP solution was pumped to each column at a flow rate of approximately 500 ml per minute. The solution was allowed to saturate the RAP material and it filled the column to approximately 2 inches higher than the RAP material. It took approximately 7 liters of the SPLP solution to fill each column. This process was repeated every fourteen days after the columns were drained.

The unsaturated columns were dosed with the SPLP solution every two days. Over a fourteen-day period, the total volume of solution added to the unsaturated columns was equal to that of the total volume added to the saturated columns. Therefore, one liter of solution was added to each column every two days. The solution was pumped at a flow rate of 50 ml/min for twenty minutes (6.47 inches/hour). The reason for adding solution at this flow rate was to try and simulate an aggressive rain storm in Florida (4 to 6 inches/hour). The volume

of solution added to each column every two days was also equivalent to 1.24 inches of rain per day.

Samples were collected every two days from the unsaturated columns and every fourteen days from the saturated columns. Samples were collected in order of sensitivity: volatile organic compounds (VOCs), semivolatiles organic compounds (Semi-VOCs), metals, and then preserved and unpreserved samples for general water quality parameter analysis. The sample containers and equipment included 40-ml glass vials, 1-liter glass jars, and 1-liter plastic jars.

3.4 LEACHATE ANALYSIS

The leachate collected was analyzed for the parameters listed in Table 3.6. Laboratory analysis was conducted according to EPA and Standard Methods (APHA, 1995) methodology for liquid aqueous samples. The cations measured included magnesium, sodium, potassium, and calcium. The anions measured included chloride, fluoride, nitrate, phosphate, and sulfate.

The pH is a measure of how acidic or basic the leachate is. Alkalinity is a measure of the ability of the leachate to neutralize hydrogen ions. Conductivity is a means to quickly gage the ionic concentration of a solution. TDS is a measure of all dissolved solids in solution, including the ions that promote conductivity. COD provides a good approximation of the amount of organic matter in the leachate (Ross, 1990). NPOC measures the amount of non-purgeable organic carbon in the leachate samples. DO measures the amount of dissolved oxygen in the leachate and can help indicate any dominant physiochemical processes that might occur in the system. ORP is a measure of the oxidation/reduction potential and helps assess whether the column is operating under reducing or oxidizing conditions.

Table 3.6 Analyzed Parameters

Analytical Test	Method
VOC Analysis	SW846-8260A
PAH Analysis	SW846-8270B
PAH Extraction	SW846-3510B
Metals Analysis	Pb-EPA 7420-21, Cr-7190-91, Zn-7950-51, Ba-7080A-81, Ca-7130-31A, Cu-7210-11, Ni-7520,
Metals Digestion (FLAA)	SW846-3010
Metals Digestion (GFAA)	SW846-3020
Alkalinity	Standard Method 2320
Anions	Standard Method 9056
Cations	EPA Method 300.7
Chemical Oxygen Demand (COD)	Standard Method 5220C
Conductivity	Standard Method 2510
Dissolved Oxygen	Standard Method 4500-OG
pH	Standard Method 4500
Oxidation/Reduction Potential (ORP)	Standard Method 2580B
Total Dissolved Solids (TDS)	Standard Method 2540C
Non Purgeable Organic Carbon (NPOC)	Standard Method 5310B

APHA (1995), US EPA (1994)

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents results from the asphalt road waste leaching project. The results reported here include the physical characterization tests performed by the FDOT, the results from the TCLP, SPLP, and DI batch leaching tests, and the results from the SPLP column leaching study. When appropriate, applicable groundwater standards or guidance concentrations are presented. Comparing the results of a leaching test with the appropriate regulatory limit typically helps assess the impact of a waste on groundwater. Appendix B contains a complete list of analytical results including all samples, lab blanks, matrix spikes, and Quality Assurance/Quality Control (QA/QC) data.

4.1 PHYSICAL CHARACTERIZATION RESULTS

The RAP samples collected from each site were physically characterized at the FDOT State Materials Lab in Gainesville, Florida by FDOT technicians. Refer to chapter three for the analytical tests and testing methods used by the FDOT lab. The results of the physical characterization of all RAP samples are presented in Table 4.1.

Table 4.1 FDOT Physical Characterization Results

Sample	Viscosity (poise)	% Asphalt Concentration	Penetration (.10mm)
Miami	118,942	6.23	16
Tampa	99,524	7.90	17
Jacksonville	969,644	6.62	8
Lake City	145,293	5.14	14
I-10 (Suwannee Cty.)	820,109	6.39	15
Indian Town Road	270,774	6.04	10

These physical characterization tests were useful in assessing the condition and age of the milled asphalt samples. As asphalt ages and is exposed to the elements, it tends to harden and become brittle. As a result the viscosity of the asphalt cement increases. The viscosity of virgin asphalt cement added to a new HMA mix is approximately 3000 poise. The viscosity of all RAP samples indicated older roadways. The Jacksonville site appeared to be the oldest. As the asphalt pavement hardens, the penetration of the RAP material should decrease. It was shown that the Jacksonville site had the smallest penetration and again was considered the oldest. The percent asphalt content of all samples were an average of 6.39%. This value is very similar to the percent asphalt cement added to new HMA mixes. There is generally minimal loss of asphalt cement over time.

The FDOT lab also performed gradation test on the RAP samples. The gradation of a design mix is usually dependent on the intended use of the material, unless otherwise stated. The Department of Transportation is responsible for setting all guidelines and regulations governing asphalt mixtures for state roads. As illustrated in Figure 4.1, all samples were of similar gradation. This was expected since the majority of the samples were taken from major

highways in Florida and the design mix for these roadways should have been similar. These results show that all samples were of comparable gradation and that there was little physical difference between them. The individual gradation results are presented in Appendix A.

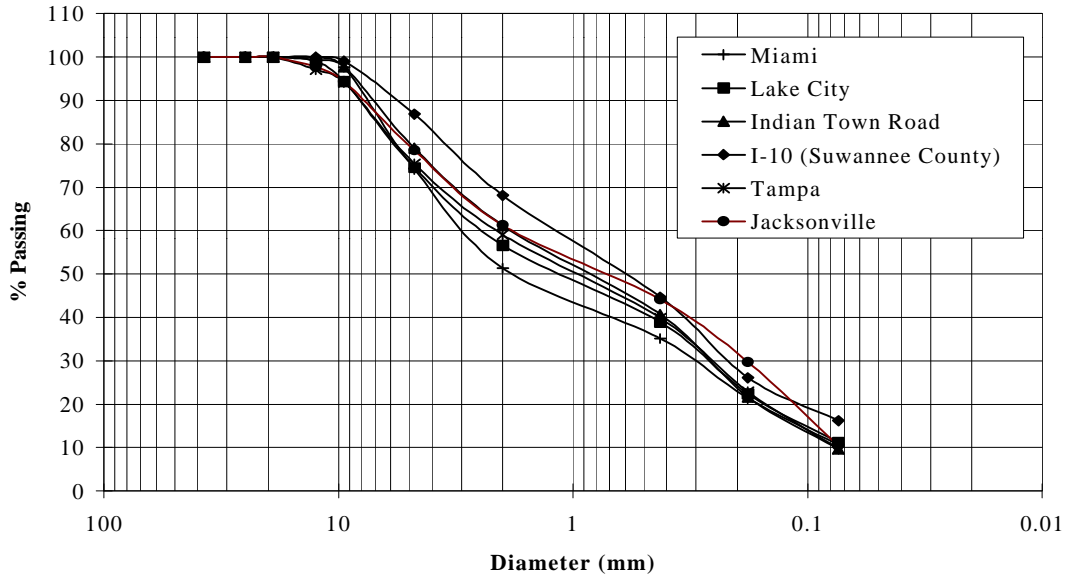


Figure 4.1 Grain Size Distribution

4.2 BATCH TEST RESULTS

The batch study was conducted prior to the lysimeter experiment. The batch leaching tests consisted of three types: the toxicity characteristic leaching procedure, the synthetic precipitation leaching procedure, and a deionized water leaching procedure. As discussed in chapter 3, the batch tests were a one-day test and produced one leachate sample for analysis. The main constituents analyzed were VOCs, PAHs, metals, and general parameters.

4.2.1 General Parameters

After the 18 hour rotation, the initial parameters measured were pH, ORP, DO, and conductivity. The results for these parameters are listed in Table 4.2.

Table 4.2 pH, ORP, DO, and Conductivity

Sample	pH			ORP (mv)			DO			Conductivity (μ s)		
	DI	TCLP	SPLP	DI	TCLP	SPLP	DI	TCLP	SPLP	DI	TCLP	SPLP
Miami	9.70	9.68	9.50	3	2	2	5.55	5.70	5.60	53.2	55.4	54.8
Tampa	9.61	9.58	9.49	3	3	3	5.25	5.30	5.37	69.5	68.5	67.6
Jacksonville	9.54	9.50	9.28	9	10	10	6.02	5.95	5.96	69.5	70.2	71.6
Lake City	9.49	9.53	9.35	5	5	4	5.55	5.40	5.46	50.3	51.2	51.7
I-10 (Suwannee Cty.)	9.50	9.60	9.34	8	8	8	5.42	5.50	5.43	55.2	54.2	53.9
Indian Town Road	9.47	9.57	9.41	6	6	7	6.41	6.45	6.49	50.4	49.8	48.7

The resulting pH of the leachate produced was consistent for all samples. The initial pH of the leaching solutions was 7.0 (DI), 4.2 (SPLP), and 4.8 (TCLP) respectively, while the final pH of the leachate produced a mean of 9.51. Since the aggregate used in the RAP material contained large amounts of calcium carbonate, the increase in pH was caused by the ability of CO_3^{-2} to neutralize the acidic nature of the leaching solution. The DO measured was consistently the same for all samples. The conductivity was similar for all samples and averaged 58 μs . The conductivity was an indirect measure of the ions released into the leachate.

The results of laboratory tests performed to test for TDS, alkalinity, COD, and NPOC are listed in Table 4.3.

Table 4.3 TDS, Alkalinity, COD, and NPOC

Sample	TDS (mg/L)			Alkalinity (mg CaCO_3/L)			COD (mg/L)			NPOC (mg/L)		
	DI	TCLP	SPLP	DI	TCLP	SPLP	DI	TCLP	SPLP	DI	TCLP	SPLP
Miami	15	18	11	20	22	22	105	115	115	20.5	21.6	22.5
Tampa	20	8	15	38	41	40	135	135	125	43.4	44.1	40.2
Jacksonville	7	5	0	42	43	43	153	144	144	42.3	42.5	44.3
Lake City	22	20	18	34	35	35	89	82	82	36.9	33.4	32.4
I-10 (Suwannee Cty.)	18	18	14	45	47	47	120	120	120	30.5	33.3	33.1
Indian Town Road	11	14	10	25	27	26	81	82	82	19.3	21.5	20.5

There were little dissolved solids in the samples with an average of 14 mg/L. The CO_3^{-2} ion, from the soluble CaCO_3 in solution, also contributed to the alkalinity. The COD and NPOC were both relatively low indicating that small levels of leachable organic material were present in the RAP samples.

4.2.2 Anions/Cations

The anions and cations analyzed for in the leachate samples were (fluoride, chloride, bromide, nitrate, sulfate) and (sodium, potassium, magnesium, calcium) respectively. These ions were dissolved into solution and contributed to other parameters such as TDS and conductivity. As a result of the sodium hydroxide used in the TCLP solution, some Na^{+1} was expected to be present. Similarly, because of the sulfuric and nitric acid used in the SPLP solution, SO_4^{-2} and NO_3^{-1} were expected to be present. The DI solution should not have any ions present. Table 4.4 lists the results for these ion measurements.

Table 4.4 Anions and Cations

Target Compounds	Miami (mg/L)	Tampa (mg/L)	Jacksonville (mg/L)	Lake City (mg/L)	I-10 (mg/L)	Indian Town Road (mg/L)
Anions						
Fluoride	1.05	1.503	1.217	1.225	BDL	1.186
Chloride	3.477	3.883	3.506	3.359	3.367	3.493
Bromide	BDL	BDL	BDL	BDL	BDL	BDL
Sulfate	5.976	8.604	11.363	5.17	6.226	5.886
Nitrate	3.437	3.434	3.57	3.276	3.424	3.368
Cations						
Sodium	BDL	BDL	1.291	BDL	BDL	BDL
Potassium	BDL	1.917	BDL	1.954	BDL	BDL
Magnesium	1.039	1.484	1.996	1.226	1.273	BDL
Calcium	8.049	11.504	16.665	9.748	25.083	10.94

*Note: Results are only for the SPLP extraction and detection limit for all was 1 mg/L

All measurements resulted in relatively low concentrations compared to secondary drinking water standards. Chloride has a limit of 250 mg/L, fluoride 2 mg/L, and sulfate 250 mg/L. Calcium was the prominent cation species measured. As mentioned earlier, the type of aggregate used to make asphalt concrete in Florida is limerock (CaCO₃). During the leaching procedure, this aggregate was dissolved into calcium and carbonate ions, as well as other trace minerals.

4.2.3 Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) were not expected to be a major concern in regard to leaching from RAP. Because of their volatility, most of these compounds would tend to evaporate quickly when spilled on the roadway or be expected to leave the RAP samples in the field.

The analytical results of volatile organic compounds in the leachate from the TCLP, SPLP, and DI tests are presented in Table 4.5. When applicable, the appropriate Florida groundwater guidance concentration is included for comparison. No VOCs on a large list of commonly encountered environmental contaminants were found above the detection limit. All results were below the detection limit (BDL) of 1 mg/L.

4.2.4 Polycyclic Aromatic Hydrocarbons (PAHs)

The analytical results of PAHs in the leachate from the TCLP, SPLP, and DI tests are presented in Table 4.6. The appropriate Florida groundwater guidance concentration is also included for comparison. Calibration curves for all PAH compounds can be found in Appendix C. The results indicated that there was no PAH occurrence greater than the groundwater guidance concentrations in the extracted leachate. For Benzo(a)pyrene, the detection limit (0.25 µg/L) was slightly higher than the guidance concentration (.20 µg/L). The responses measured by the mass spectrometer for the chromatogram retention time where Benzo(A)pyrene occurred, indicated no difference relative to the chromatogram of a deionized water blank.

Table 4.5 Volatile Organic Compounds

Target Compounds	Miami (µg/L)	Tampa (µg/L)	Jacksonville (µg/L)	Lake City (µg/L)	I-10 (µg/L)	Indian Town Road (µg/L)	Detection Limit (µg/L)	GW Guidance Concentration (µg/L)
bromomethane	BDL	BDL	BDL	BDL	BDL	BDL	1	10
chloroethane	BDL	BDL	BDL	BDL	BDL	BDL	1	140
trichlorofluoromethane	BDL	BDL	BDL	BDL	BDL	BDL	1	2100
1,1-dichloroethene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
methylene chloride	BDL	BDL	BDL	BDL	BDL	BDL	1	2.7
trans-1,2-dichloroethene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,1-dichloroethane	BDL	BDL	BDL	BDL	BDL	BDL	1	700
1,2-dichloropropane	BDL	BDL	BDL	BDL	BDL	BDL	1	5
cis-1,2-dichloroethene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
bromochloromethane	BDL	BDL	BDL	BDL	BDL	BDL	1	.6
chloroform	BDL	BDL	BDL	BDL	BDL	BDL	1	6
carbon tetrachloride	BDL	BDL	BDL	BDL	BDL	BDL	1	3
1,1-dichloropropene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
benzene	BDL	BDL	BDL	BDL	BDL	BDL	1	1
trichloroethene	BDL	BDL	BDL	BDL	BDL	BDL	1	2
dibromomethane	BDL	BDL	BDL	BDL	BDL	BDL	1	.02
1,3-dichloropropane	BDL	BDL	BDL	BDL	BDL	BDL	1	-
toluene	BDL	BDL	BDL	BDL	BDL	BDL	1	1000
trans-1,3-dichloropropene	BDL	BDL	BDL	BDL	BDL	BDL	1	1
1,1,2-trichloroethane	BDL	BDL	BDL	BDL	BDL	BDL	1	5
tetrachloroethene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
cis-1,3-dichloropropene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
dibromochloromethane	BDL	BDL	BDL	BDL	BDL	BDL	1	1
1,2-dibromoethane	BDL	BDL	BDL	BDL	BDL	BDL	1	.02
chlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,1,1,2-tetrachloroethane	BDL	BDL	BDL	BDL	BDL	BDL	1	1
ethylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	700
m/p-xylene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
o-xylene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
total-xylene	BDL	BDL	BDL	BDL	BDL	BDL	1	10000
styrene	BDL	BDL	BDL	BDL	BDL	BDL	1	100
bromoform	BDL	BDL	BDL	BDL	BDL	BDL	1	4
isopropylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	.8
bromobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,2,3-trichloropropane	BDL	BDL	BDL	BDL	BDL	BDL	1	42
1,1,2,2-tetrachloroethane	BDL	BDL	BDL	BDL	BDL	BDL	1	1
n-propylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
2-chlorotoluene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
4-chlorotoluene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,2,4-trimethylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	10
n-butylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,3,5-trimethylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	10
sec-butylbenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,3-dichlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	10
1,4-dichlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	75
4-isopropyltoluene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
1,2-dichlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	600
1,2,3-trichlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	-
Naphthalene	BDL	BDL	BDL	BDL	BDL	BDL	1	6.8
1,2,4-trichlorobenzene	BDL	BDL	BDL	BDL	BDL	BDL	1	70

*Note: BDL = Below Detection Limit and results are for TCLP, SPLP, and DI test

To confirm that samples were below the guidance concentration, additional tests were performed on twelve of the most aggressive samples. A list of the twelve samples is provided in Appendix A. Initially, samples were concentrated down to 2 ml following method 8270 for semivolatile extractions with a resulting detection limit of 0.25 µg/L. During the additional tests, the twelve samples were concentrated down to 1 ml, which resulted in a detection limit

of 0.125 µg/L. All twelve of these samples did not detect Benzo(A)pyrene, even at the lower detection limit.

Table 4.6 Polycyclic Aromatic Hydrocarbons

Target Compounds	Miami (µg/L)	Tampa (µg/L)	Jacksonville (µg/L)	Lake City (µg/L)	I-10 (µg/L)	Indian Town Road (µg/L)	Detection Limit (µg/L)	GW Guidance Concentration (µg/L)
Acenaphthene	BDL	BDL	BDL	BDL	BDL	BDL	5	20
Acenaphthylene	BDL	BDL	BDL	BDL	BDL	BDL	5	10
Anthracene	BDL	BDL	BDL	BDL	BDL	BDL	5	2100
Benzo[a]anthracene	BDL	BDL	BDL	BDL	BDL	BDL	5	4
Benzo[a]pyrene	BDL	BDL	BDL	BDL	BDL	BDL	.25	.2
Benzo[b]fluoranthene	BDL	BDL	BDL	BDL	BDL	BDL	1	4
Benzo[ghi]perylene	BDL	BDL	BDL	BDL	BDL	BDL	5	10
Benzo[k]fluoranthene	BDL	BDL	BDL	BDL	BDL	BDL	2.5	4
Chrysene	BDL	BDL	BDL	BDL	BDL	BDL	5	5
Dibenz[a,h]anthracene	BDL	BDL	BDL	BDL	BDL	BDL	2.5	7.5
Fluoranthene	BDL	BDL	BDL	BDL	BDL	BDL	5	280
Fluorine	BDL	BDL	BDL	BDL	BDL	BDL	1	280
Indeno[1,2,3-cd]pyrene	BDL	BDL	BDL	BDL	BDL	BDL	1	7.5
Napthalene	BDL	BDL	BDL	BDL	BDL	BDL	1	6.8
Phenanthrene	BDL	BDL	BDL	BDL	BDL	BDL	2.5	10
Pyrene	BDL	BDL	BDL	BDL	BDL	BDL	.5	210

*Note: BDL = Below Detection Limit and results are for TCLP, SPLP, and DI test

4.2.5 Heavy Metals

Heavy metals are often cited as a concern when dealing with materials from roadways. Vehicle wear, fuel emissions, and fuel leakage could all result in contamination with heavy metals. Leachate samples were analyzed on both the Flame AA spectrometer and Graphite Furnace AA spectrometer in order to reach a detection limit below the groundwater guidance concentration. The metals tested were those commonly found in previous studies. The results of the analysis for selected heavy metals are presented in Table 4.7. No concentrations of the selected heavy metals in the extracted leachate were detected greater than the groundwater guidance concentrations.

Table 4.7 Heavy Metals

Target Compounds	Miami (mg/L)	Tampa (mg/L)	Jacksonville (mg/L)	Lake City (mg/L)	I-10 (mg/L)	Indian Town Road (mg/L)	Detection Limit (mg/L)	GW Guidance Concentration (mg/L)
Barium	BDL	BDL	BDL	BDL	BDL	BDL	0.5	2
Cadmium	BDL	BDL	BDL	BDL	BDL	BDL	.005	.005
Chromium	BDL	BDL	BDL	BDL	BDL	BDL	0.1	0.1
Copper	BDL	BDL	BDL	BDL	BDL	BDL	0.5	1
Lead	BDL	BDL	BDL	BDL	BDL	BDL	.010	.015
Nickel	BDL	BDL	BDL	BDL	BDL	BDL	0.1	0.1
Zinc	BDL	BDL	BDL	BDL	BDL	BDL	0.5	5

*Note: BDL = Below Detection Limit and results are for TCLP, SPLP, and DI test

4.3 LYSIMETER STUDY RESULTS

While the batch tests were used to assess pollutant leaching according to existing regulatory policies, the lysimeter study was performed to simulate more realistic environmental conditions. As discussed earlier, two environmental conditions were simulated: unsaturated conditions and saturated conditions

The columns were loaded on December 14, 1997 and proceeded forty days until January 25, 1998. Table 4.8 lists the sampling date and the appropriate sampling day. The parameters analyzed included VOCs, PAHs, metals, and conventional water quality parameters. For a comparison purpose, it should be noted that these were the same as the batch test. A control blank (no RAP) and a duplicate (Indian Town Road) were used to ensure the integrity of the results. The leachate volume collected is presented in Appendix D.

Table 4.8 Sampling Date and Sampling Day

Sample Date	Sample Day
12/18/97	2
12/20/97	4
12/22/97	6
12/24/97	8
12/26/97	10
12/28/97	12
12/30/97	14
1/1/98	16
1/3/98	18
1/5/98	20
1/7/98	22
1/9/98	24
1/11/98	26
1/13/98	28
1/15/98	30
1/17/98	32
1/19/98	34
1/21/98	36
1/23/98	38
1/25/98	40

4.3.1 General Water Quality Parameters

After sample collection, the initial parameters measured were pH, DO, and conductivity. Graphs for the individual parameters and for all lysimeters are presented below. All graphs plot concentration versus sample day. Figure 4.2 and Figure 4.3 show the different pH ranges for the unsaturated and saturated lysimeters, respectively.

The initial pH of the unsaturated lysimeters started out around 7 and then gradually increased to approximately 7.5 over the next 28-days. After this time it began to level off around 7. The initial pH of the leaching solution added to the system was 4.20. The increase in pH was attributed to the release of CO_3^{+2} species from the aggregate in the lysimeters. The CO_3^{+2} ions neutralized the acidic nature of the SPLP solution and buffered the leachate, thus causing an increase in pH. For the saturated lysimeters, the pH remained close to 7.5. It should be noted that the pH increase measured in the control column was also attributed to the CO_3^{+2} ions dissolved from the sand distribution layer. It can therefore be stated that although

rainwater has a slightly acidic pH, the actual solution conditions in a RAP stockpile will be neutral from carbonate alkalinity in the aggregate.

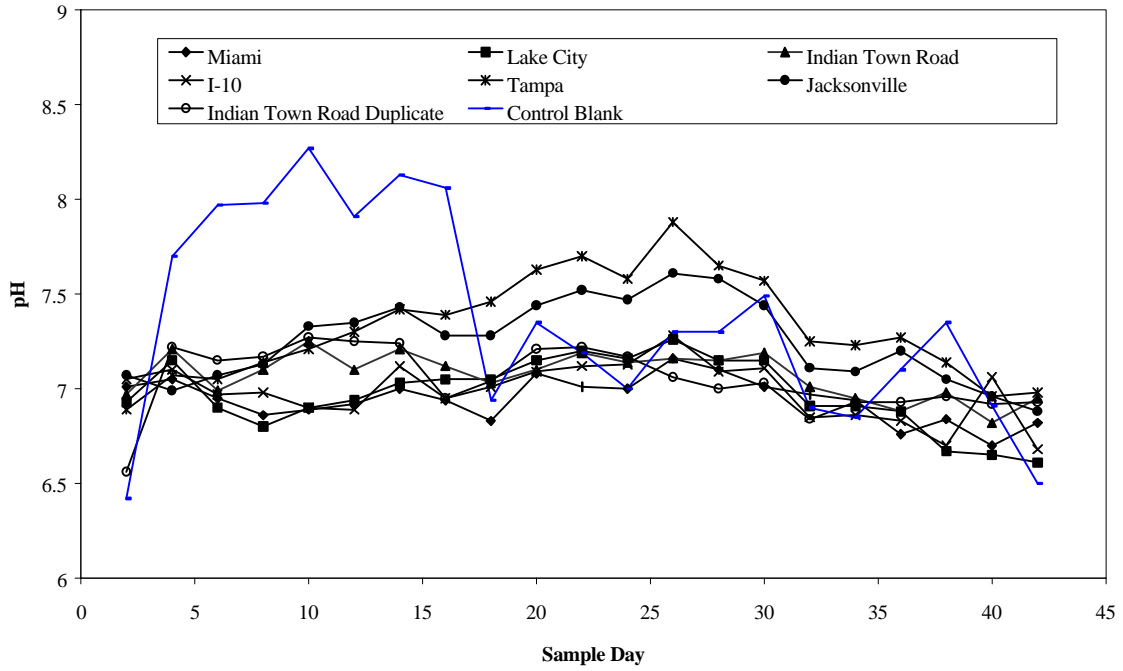


Figure 4.2 Unsaturated pH vs. Time

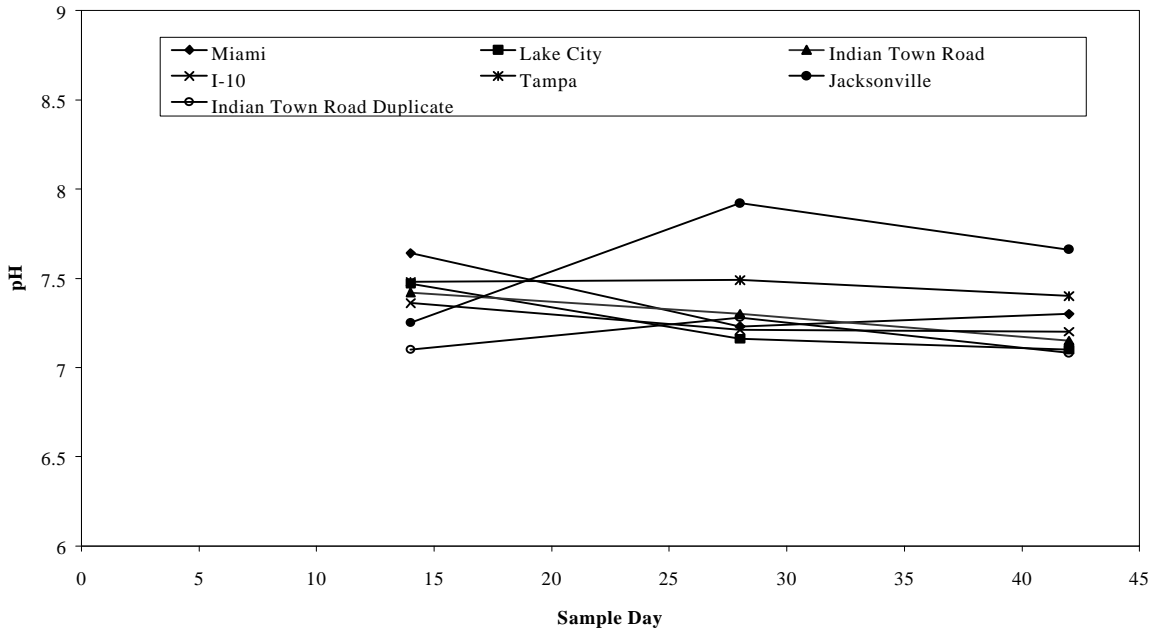


Figure 4.3 Saturated pH vs. Time

Figure 4.4 and Figure 4.5 show the DO measurements for the unsaturated and saturated lysimeters. DO is a measurement of the dissolved oxygen in the leachate.

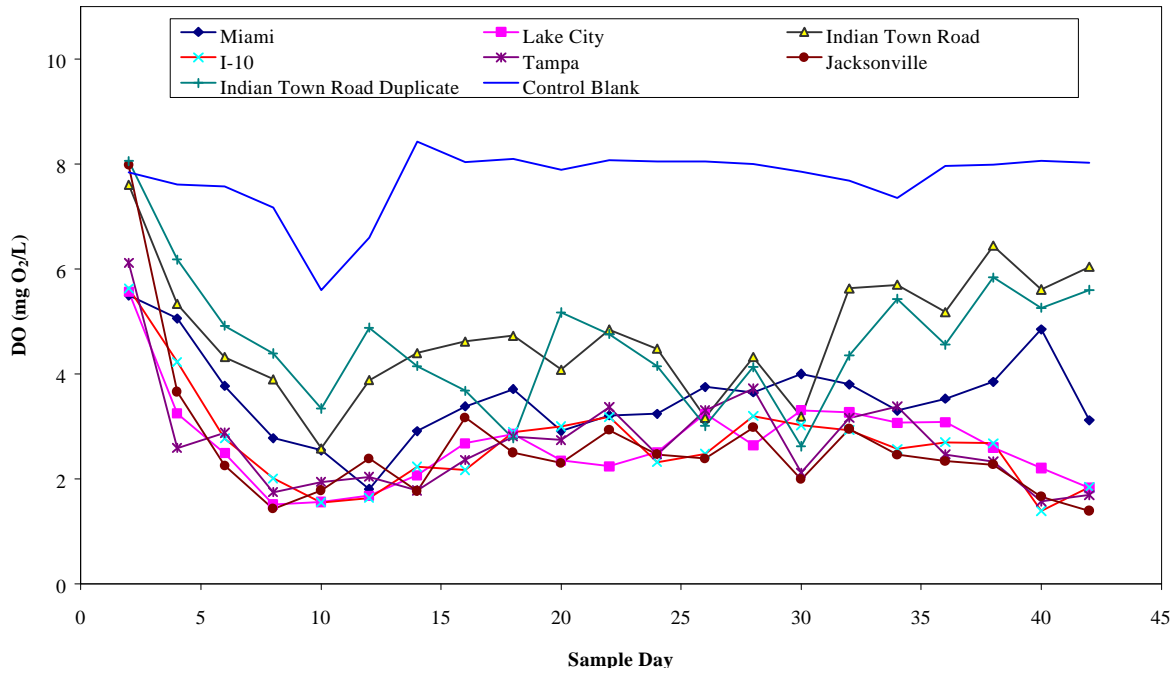


Figure 4.4 Unsaturated DO vs. Time

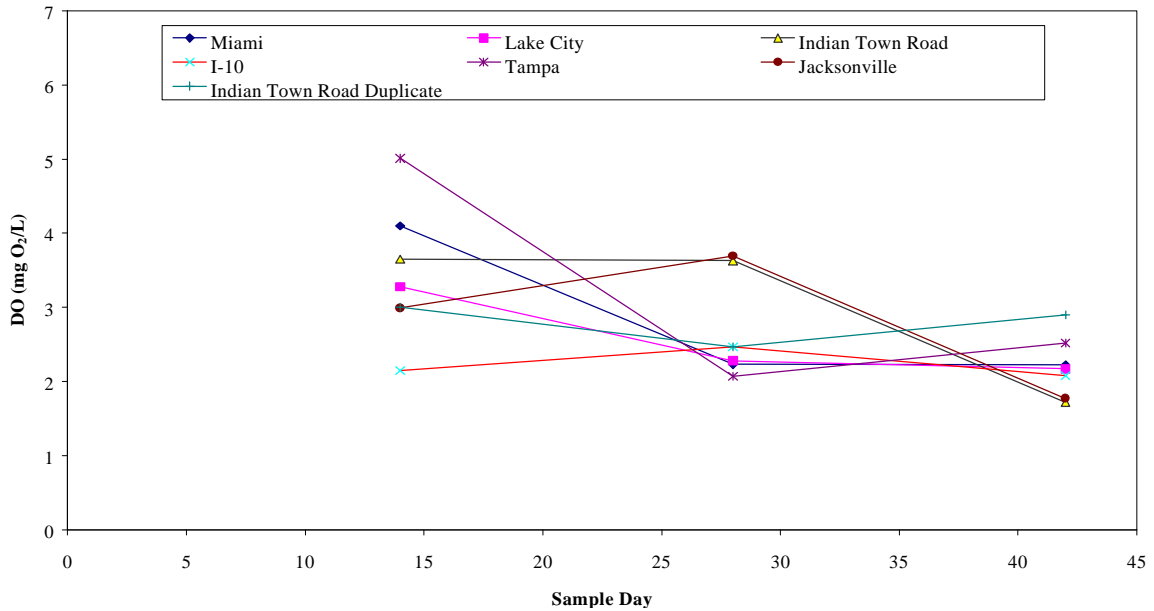


Figure 4.5 Saturated DO vs. Time

The DO in the unsaturated lysimeters initially started off between 6 and 8 mg O₂/L. Over the sample period, the DO leveled off into a range of 2 to 6 mg O₂/L for lysimeters 1 through 7. The control blank stayed relatively constant at approximately 7.5 mg O₂/L. In the saturated lysimeters, the DO stayed in the range of 2 to 5 mg O₂/L but dropped slightly over time. This slight decline occurred in both column situations. The results indicated that reactions occurring in the columns were exerting some oxygen demand.

Figure 4.6 and Figure 4.7 show the conductivity of the leachate samples over time. The conductivity was used to measure the dissolved ion species in the leachate solution.

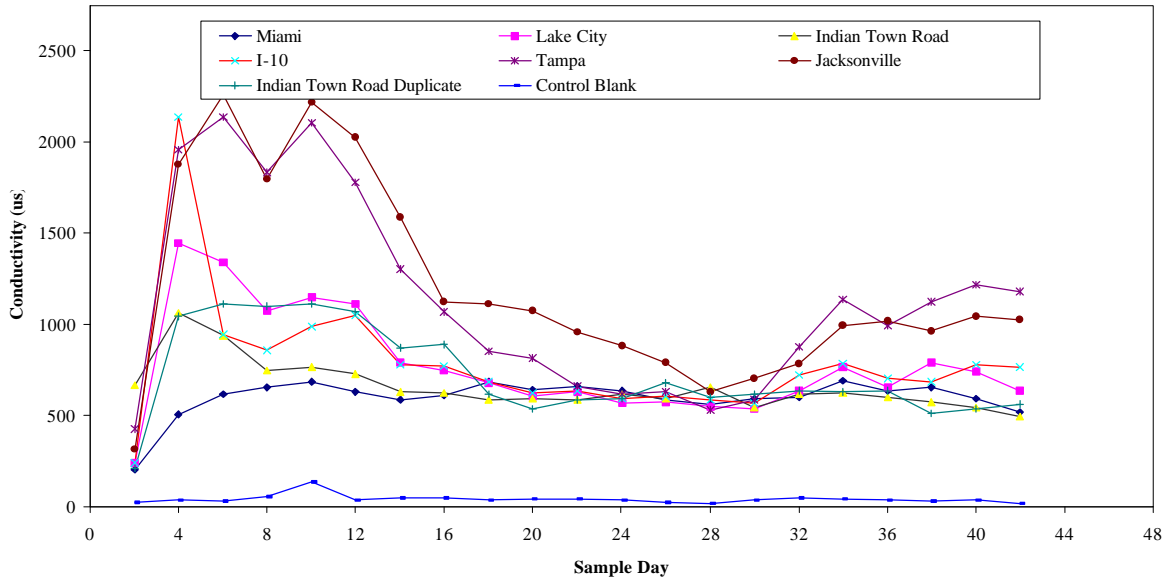


Figure 4.6 Unsaturated Conductivity vs. Time

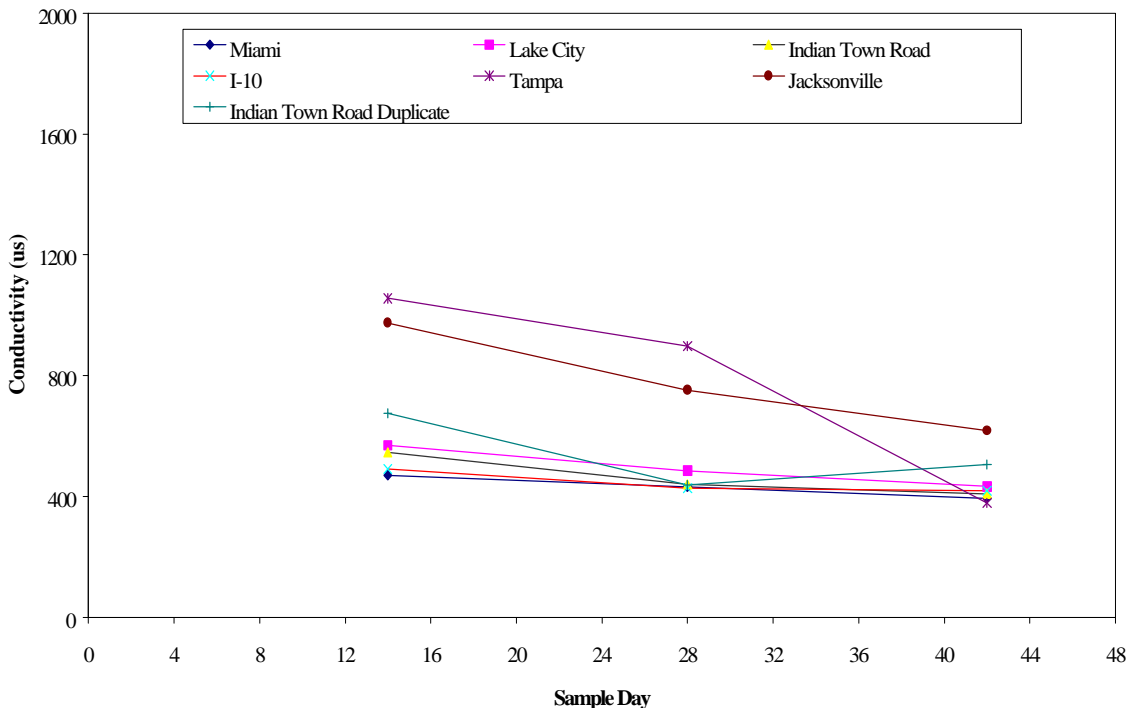


Figure 4.7 Saturated Conductivity vs. Time

The conductivity started around 500 μs and then increased rapidly over the next six days to a maximum of 2,300 μs . At this point the conductivity started to decrease and quickly leveled off around 600 μs . A slight increase in conductivity occurred soon after but started to decrease around 600 μs over time.

All RAP samples illustrated the typical leaching curve as the initial “first flush” of the ions occurred and then soon decreased over time. The term “first flush” refers to the release of the greatest concentration of contaminants in the beginning stages of leaching. The control blank remained constant around 50 μs as was expected. The small amount of conductivity found in the control blank was attributed to the ion species dissolved from the drainage sand and SPLP solution. The small increase in conductivity at the end of the experiment was potentially the result of a different flow pattern in the lysimeters, thus dissolving more ionic species. The saturated columns follow the same pattern for conductivity, as did the unsaturated columns. The conductivity started out high and decreased over time.

Laboratory tests were then performed to test for TDS, alkalinity, COD, and NPOC. Figure 4.8 and Figure 4.9 show the results for unsaturated and saturated TDS.

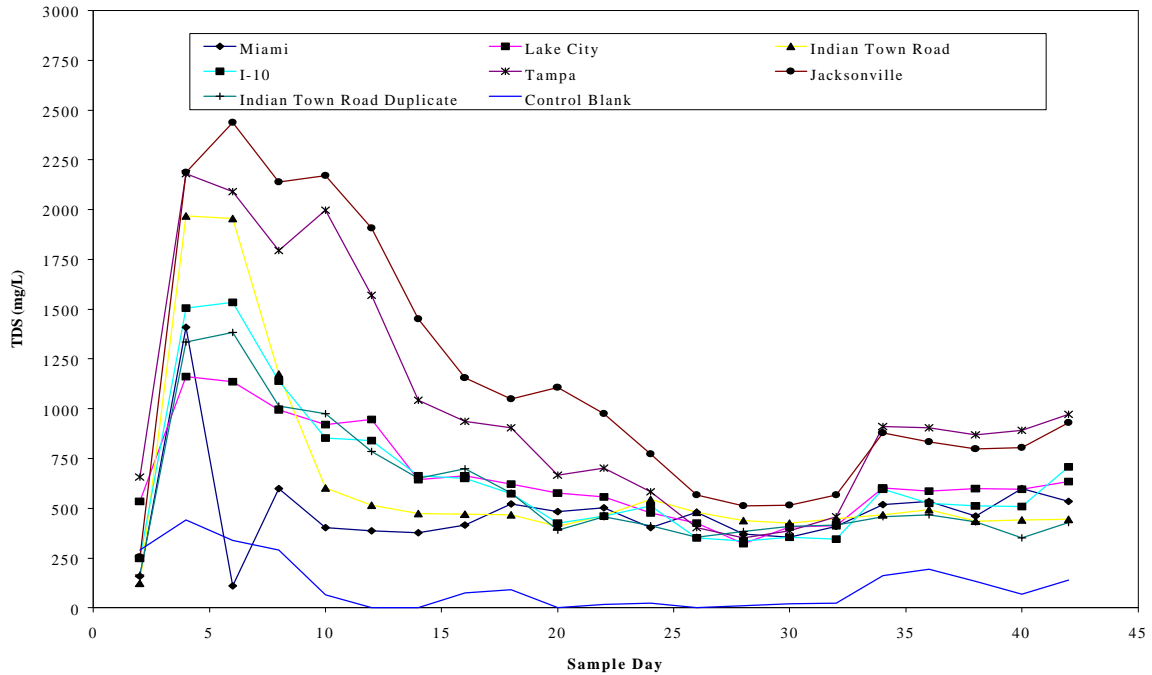


Figure 4.8 Unsaturated TDS vs. Time

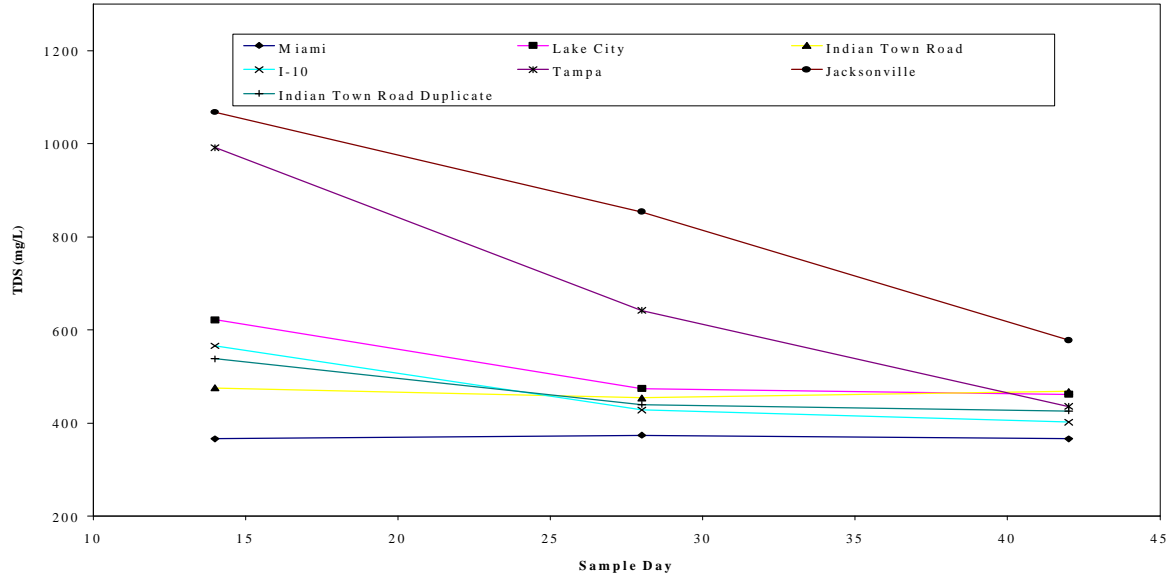


Figure 4.9 Saturated TDS vs. Time

The TDS for the unsaturated columns followed the typical leaching curve. The TDS started out low and then increased to values close to 2,500 mg/L. The TDS then decreased and leveled off around 500 mg/L. A slight increase was observed toward the end of the experiment in some of the unsaturated columns. This slight increase at the end was attributed to new flow patterns in the columns, or simply experimental error.

All RAP samples reached TDS measurements above the secondary drinking water standard of 500 mg/L. As will be seen later, the TDS was a result of mineral leaching from the aggregate, and would be similar to any limestone aggregate. The saturated columns also illustrated a decrease in TDS over time. Both saturated and unsaturated columns had measurements above the secondary drinking water limits of 500 mg/L. The results for alkalinity are presented in Figure 4.10 and 4.11.

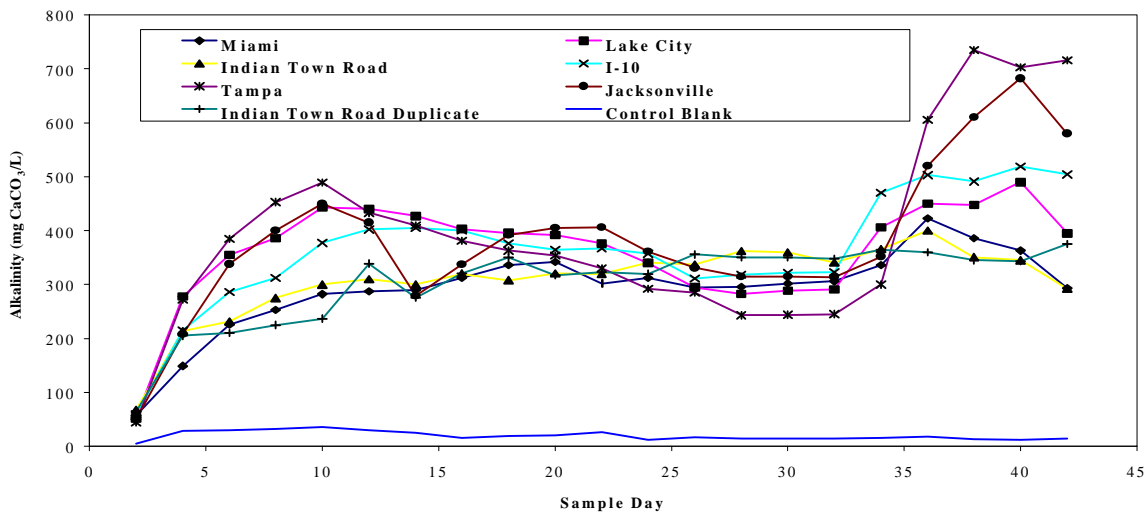


Figure 4.10 Unsaturated Alkalinity vs. Time

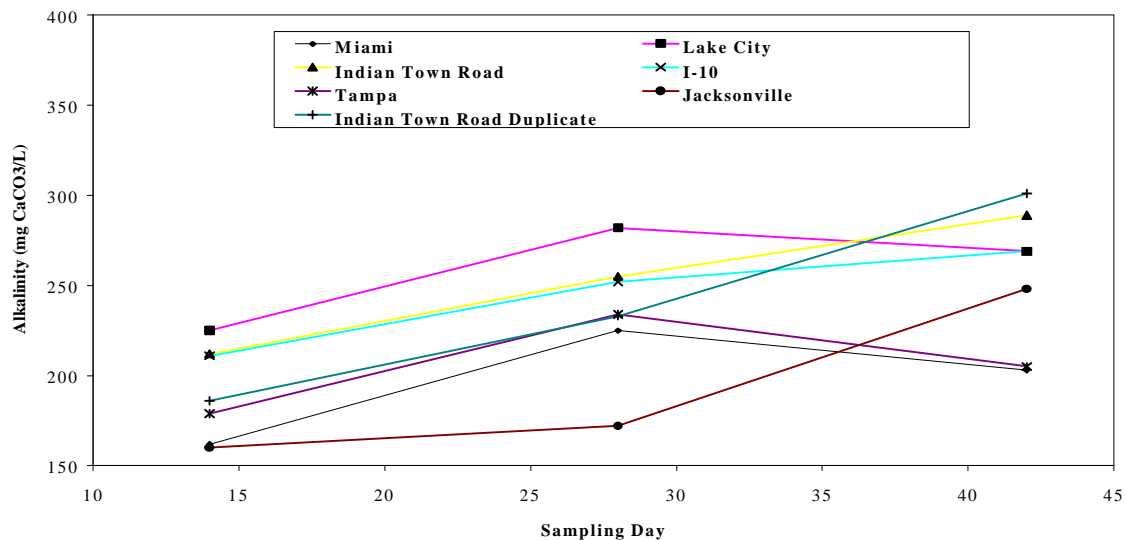


Figure 4.11 Saturated Alkalinity vs. Time

Alkalinity (attributed to the carbonate aggregate), increased somewhat over time, but remained relatively constant during most of the unsaturated experiment. Towards the end of the experiment the alkalinity showed a more dramatic increase and then leveled off again. Since alkalinity was attributed to the release of CO_3^{-2} into solution, the conclusion was that a changed flow pattern caused more of these ions to be dissolved.

Figure 4.12 and Figure 4.13 display the COD results for the unsaturated and saturated lysimeters. COD measurements were useful in estimating the amount of organics in the leachate.

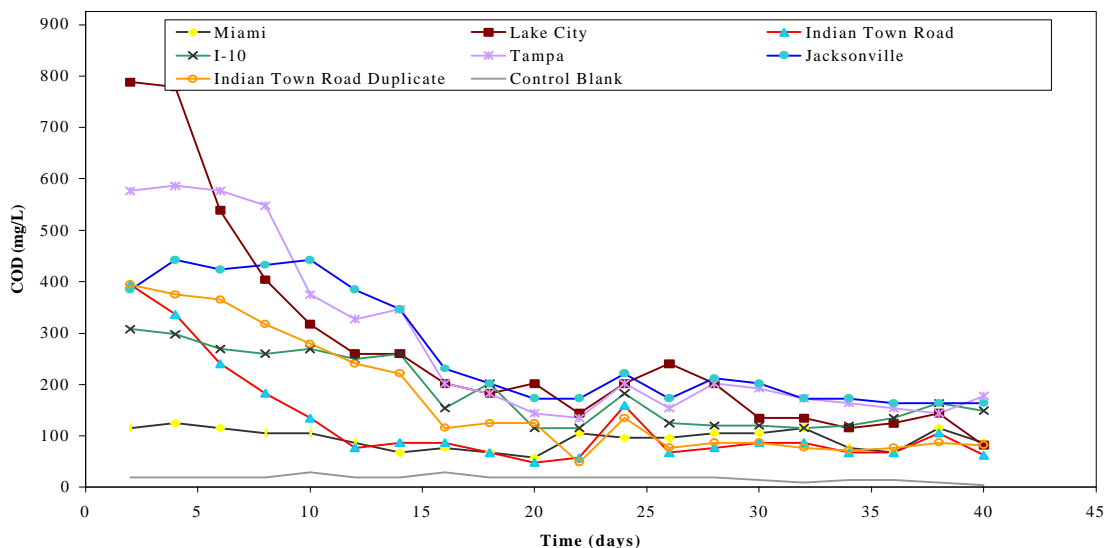


Figure 4.12 Unsaturated COD vs. Time

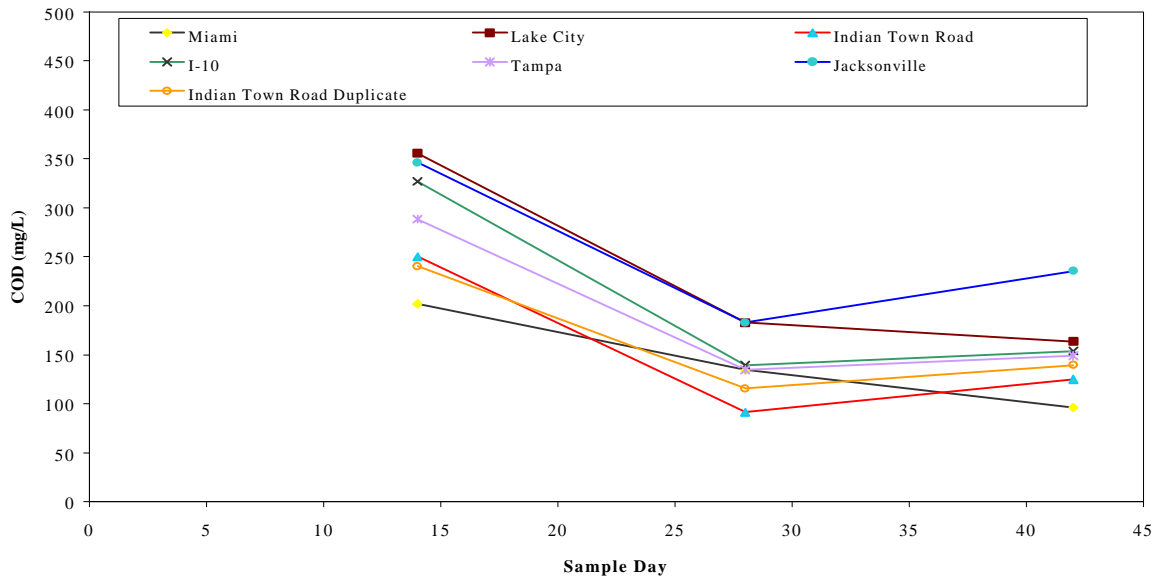


Figure 4.13 Saturated COD vs. Time

In the unsaturated columns, the typical leaching curve was illustrated. The initial COD values ranged from 300-800 mg/L but soon decreased to a constant value of approximately 200 mg/L. The saturated columns also decreased over time. The decrease in organic matter in the system contributed to the decrease in COD. Without the organic matter to be oxidized the COD demand goes down.

NPOC results are illustrated in Figure 4.14 and Figure 4.15. NPOC was also used to estimate the amount of organic material in the leachate samples. The trend illustrated with NPOC results were similar the COD results, as was expected. The unsaturated column illustrated the leaching curve and the saturated column decreased over the sampling period. Although some organic matter was leached, its nature was not characterized. Priority pollutant organic compounds are discussed in the next section.

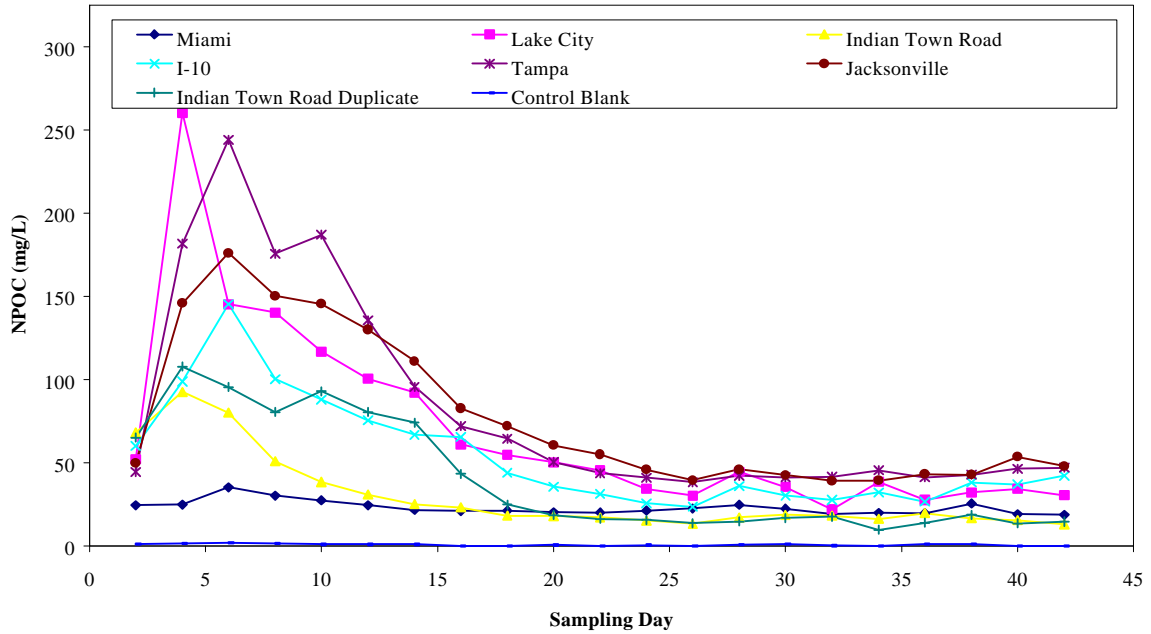


Figure 4.14 Unsaturated NPOC vs. Time

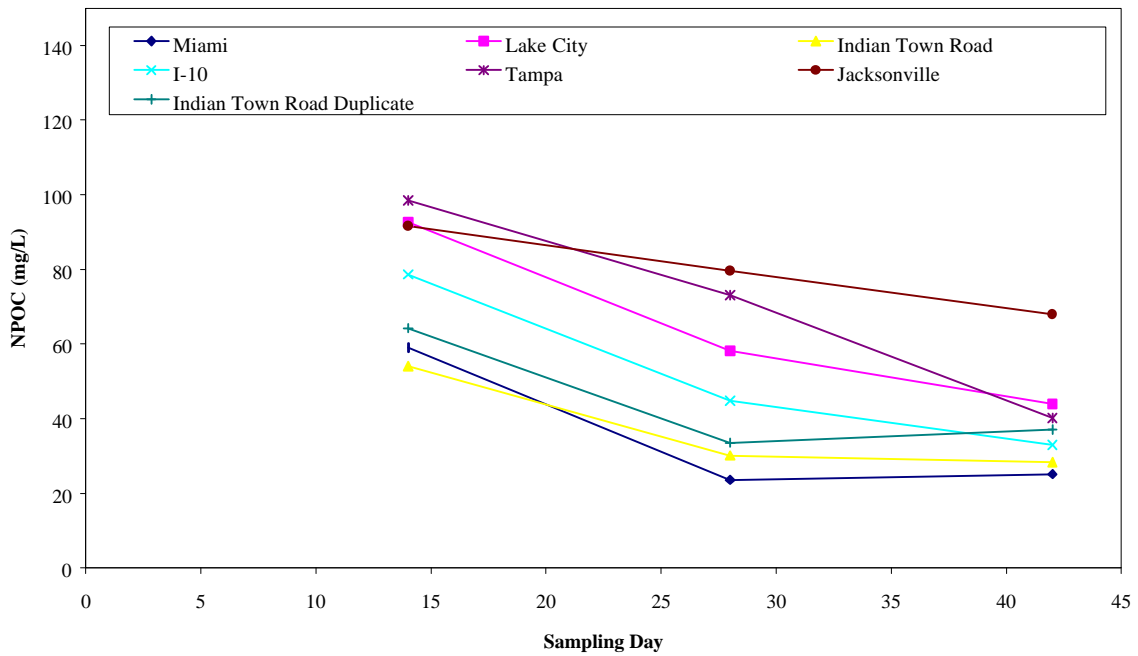


Figure 4.15 Saturated NPOC vs. Time

4.3.2 Anions/Cations

As discussed earlier, the anions and cations tested for in the leachate samples were (fluoride, chloride, bromide, nitrate, sulfate) and (sodium, potassium, magnesium, and calcium). The presence of these ions also contributed to TDS and conductivity measurements. Dissolved ions such as SO_4^{-2} and NO_3^{-1} were expected due to the nature of the leaching solutions used in the experiments. Figure 4.16 through Figure 4.19 and Figure 4.24 through Figure 4.27

illustrate the results for anion analysis. Figure 4.20 through Figure 4.23 and Figure 4.28 through Figure 4.31 illustrate the results for cation analysis.

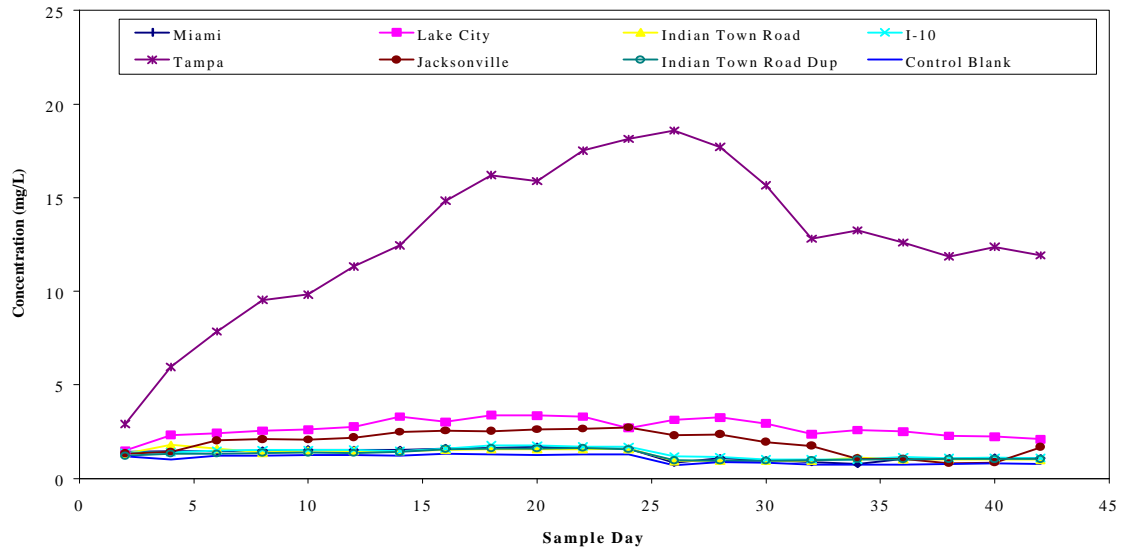


Figure 4.16 Unsaturated Fluoride vs. Time

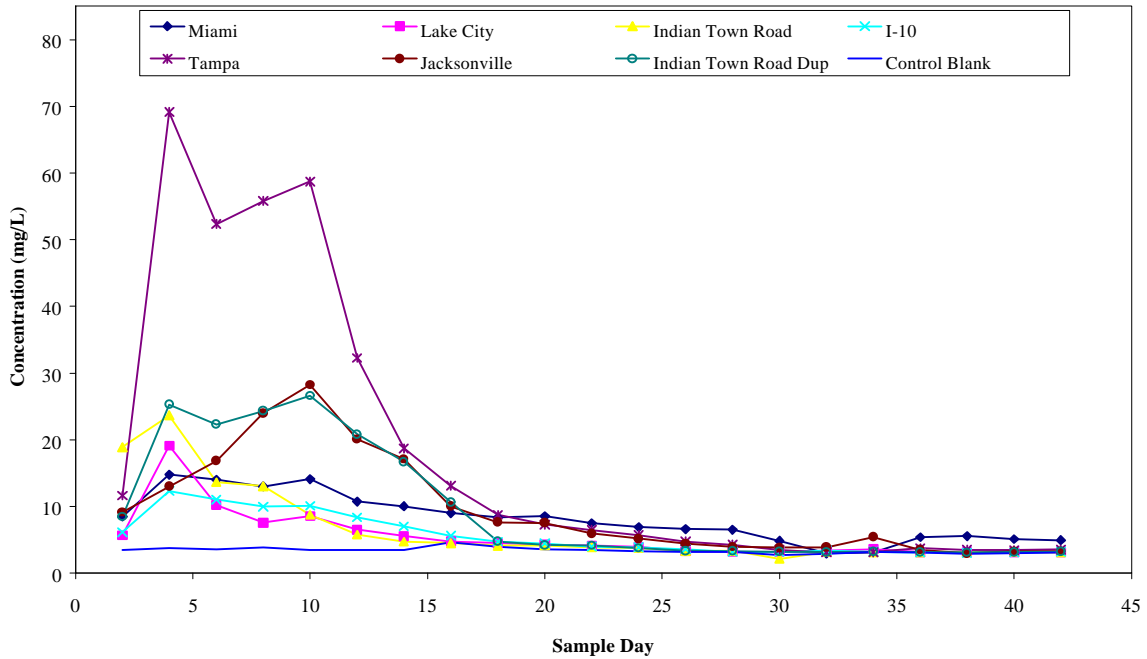


Figure 4.17 Unsaturated Chloride vs. Time

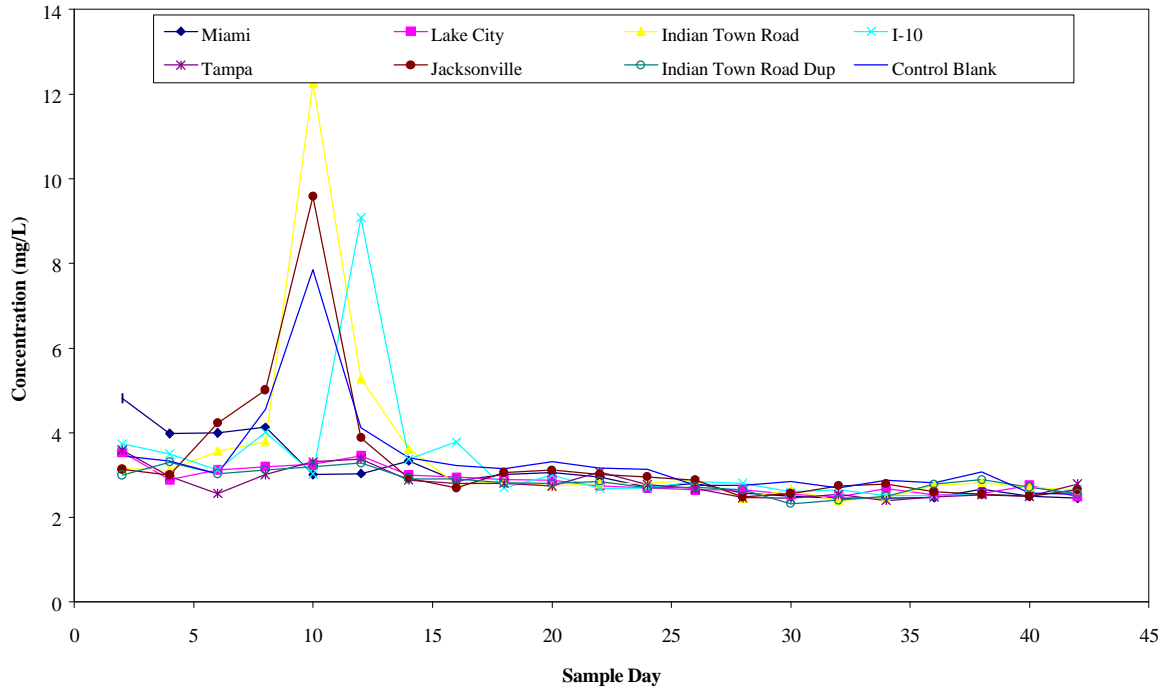


Figure 4.18 Unsaturated Nitrate vs. Time

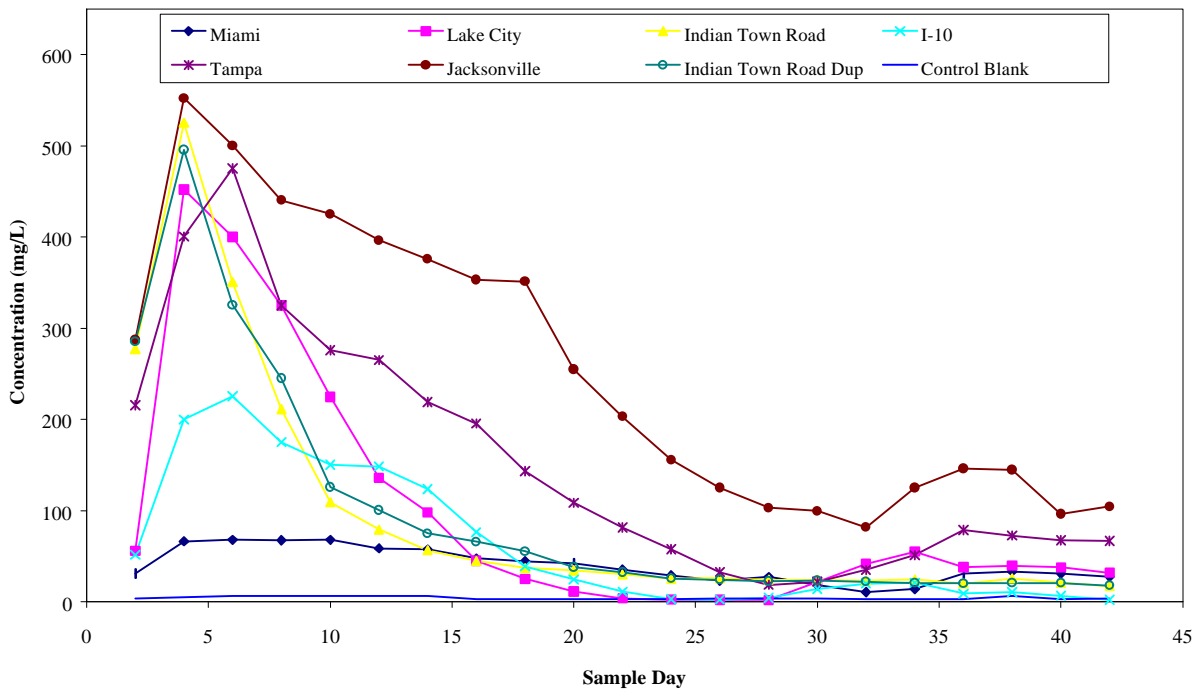


Figure 4.19 Unsaturated Sulfate vs. Time

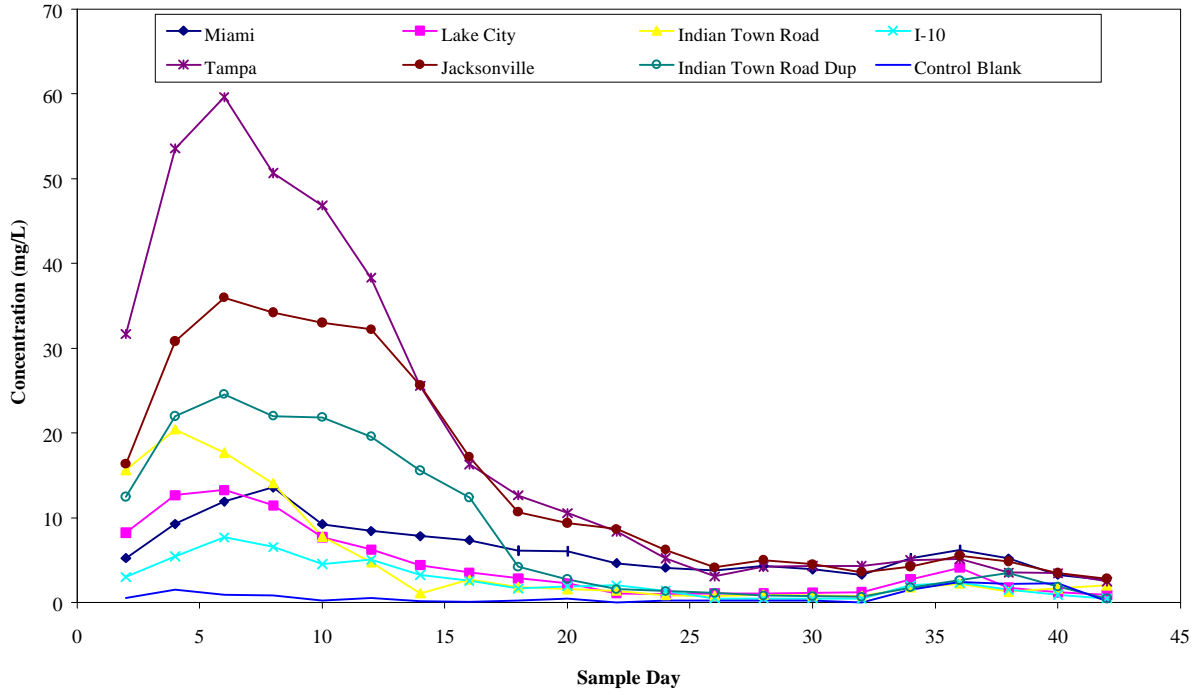


Figure 4.20 Unsaturated Sodium vs. Time

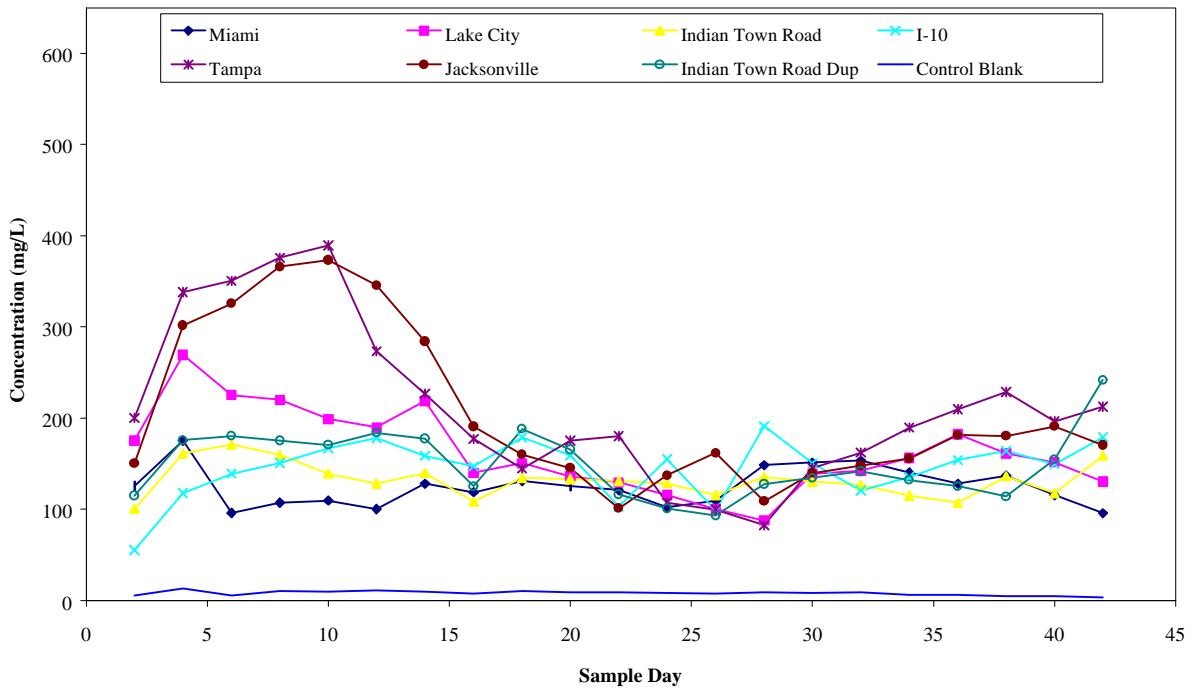


Figure 4.21 Unsaturated Calcium vs. Time

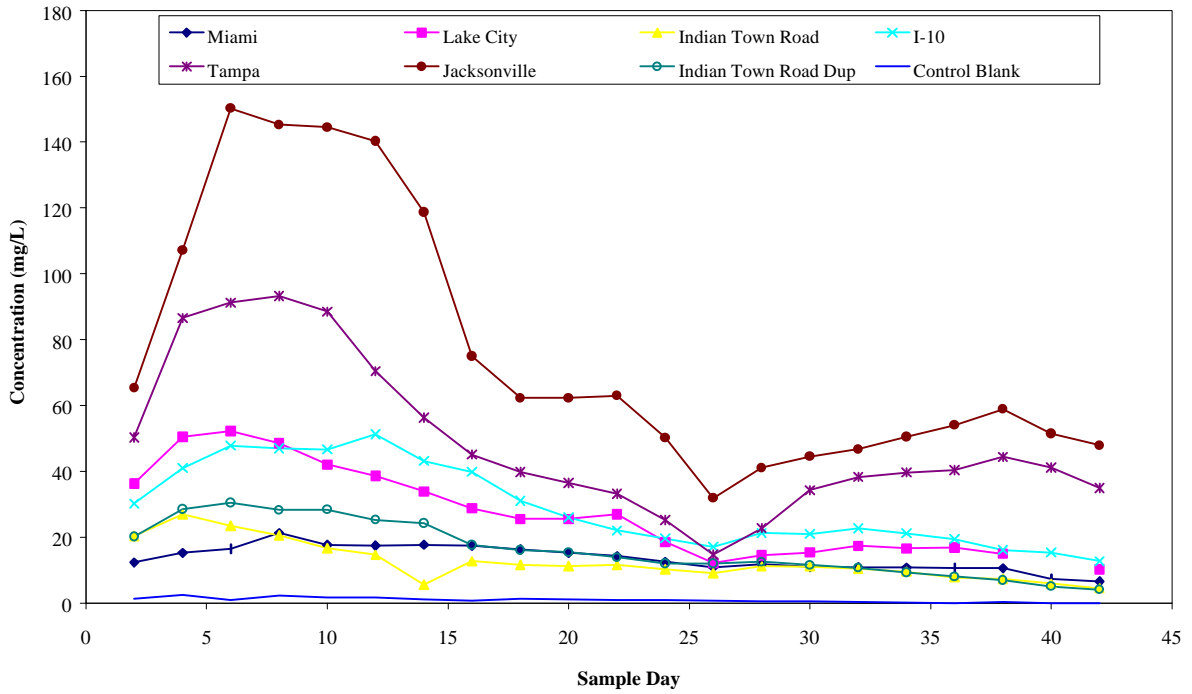


Figure 4.22 Unsaturated Magnesium vs. Time

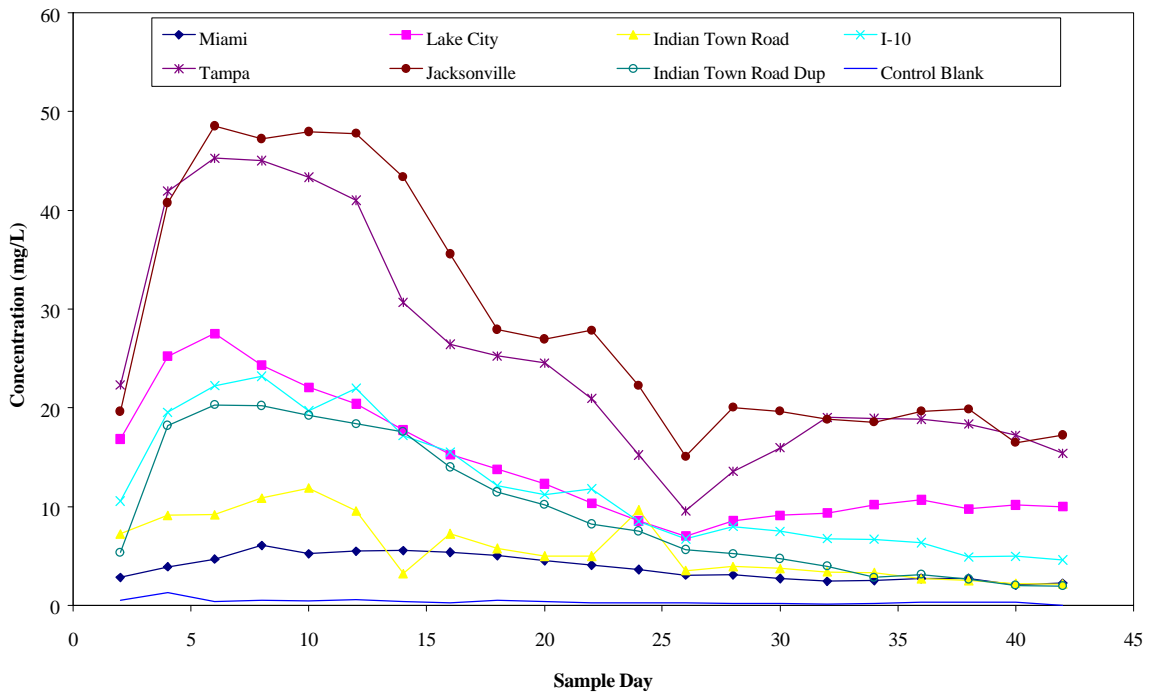


Figure 4.23 Unsaturated Potassium vs. Time

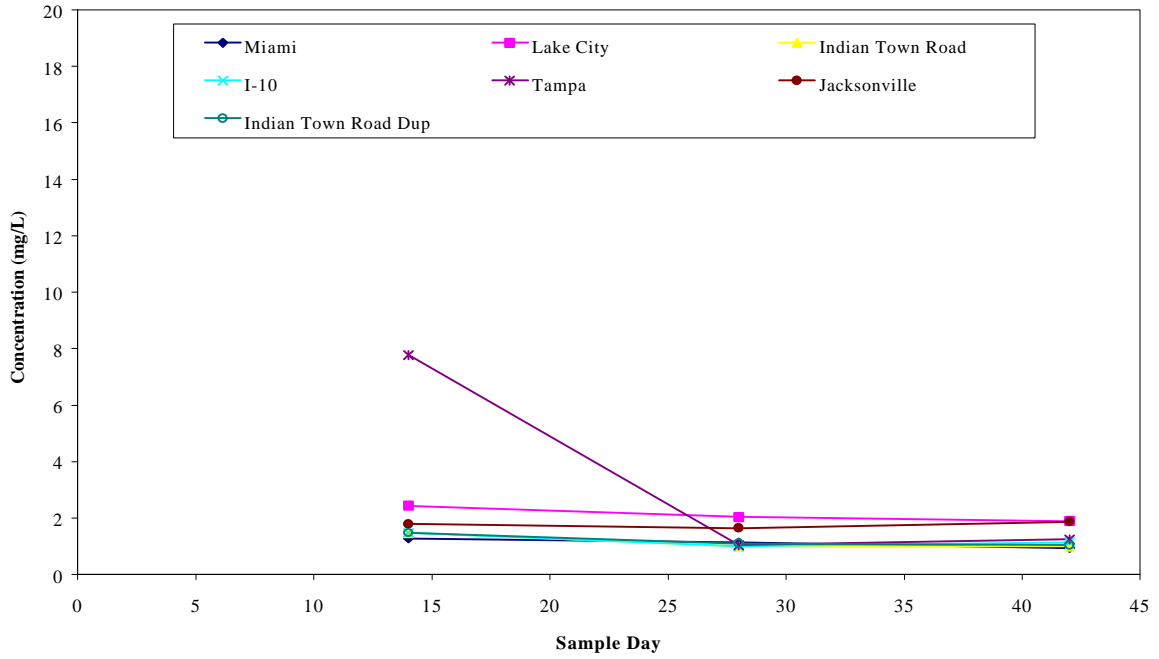


Figure 4.24 Saturated Fluoride vs. Time

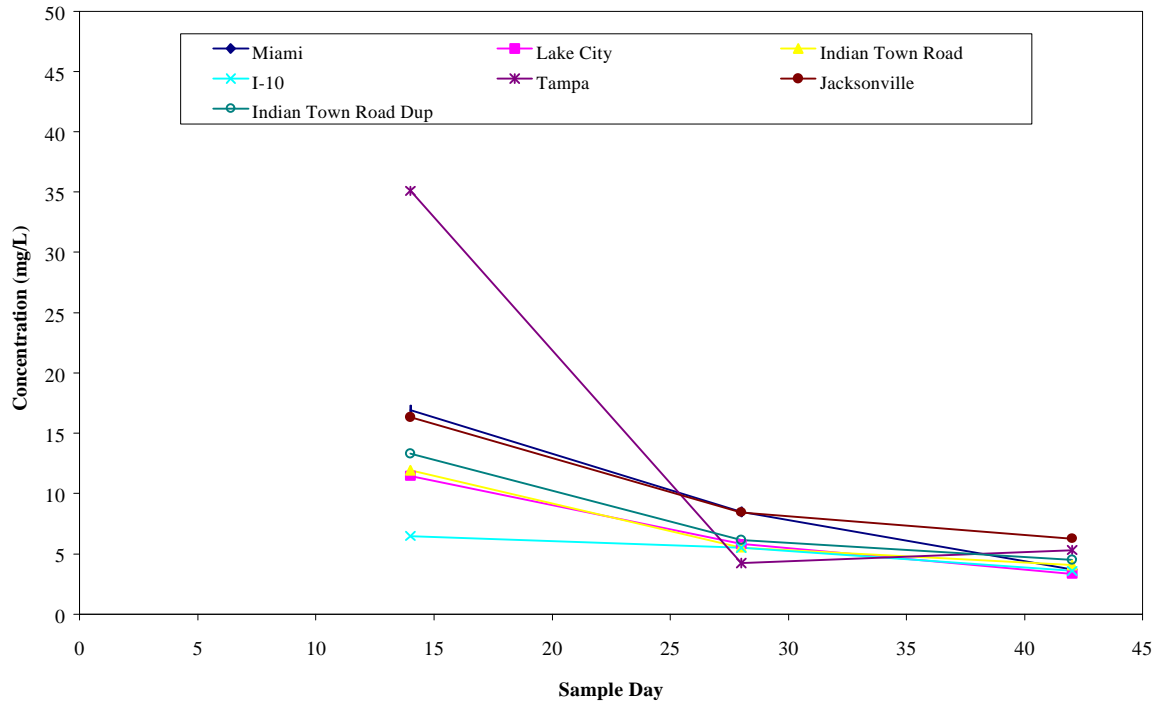


Figure 4.25 Saturated Chloride vs. Time

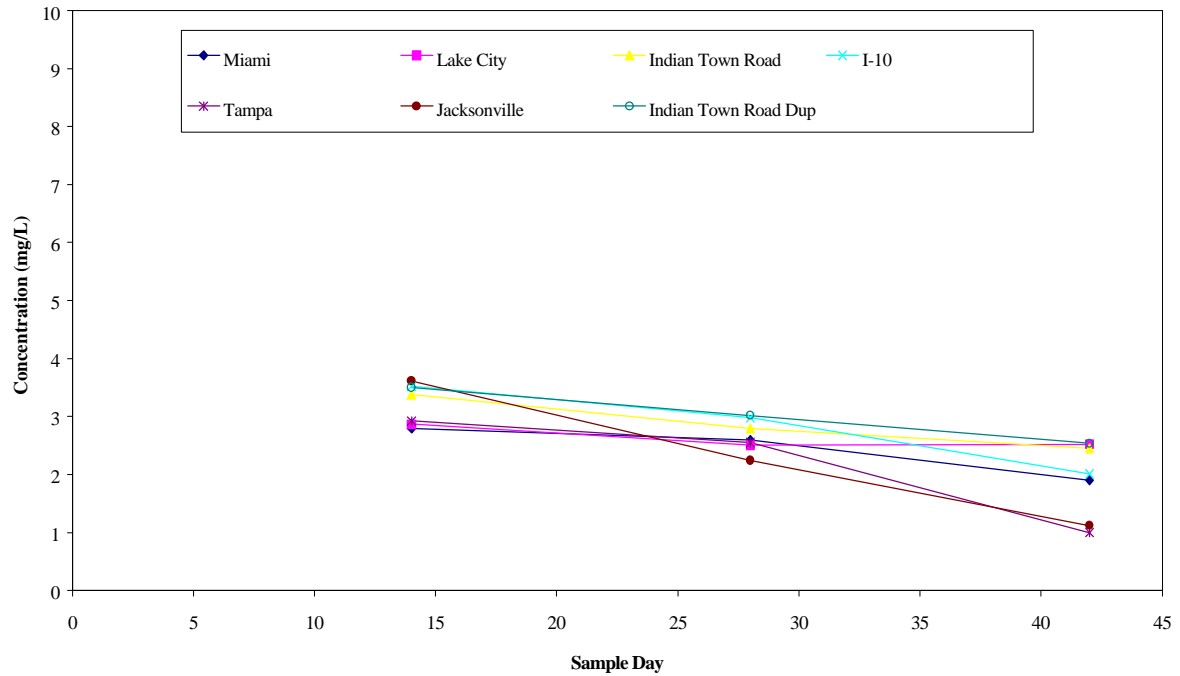


Figure 4.26 Saturated Nitrate vs. Time

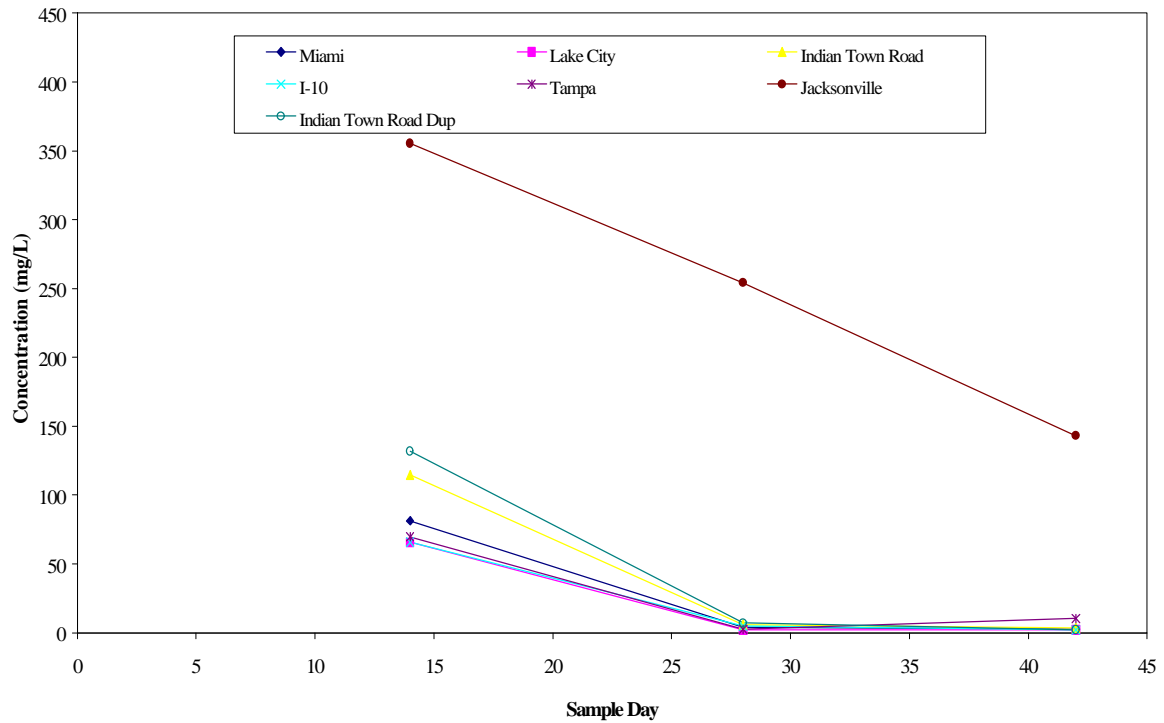


Figure 4.27 Saturated Sulfate vs. Time

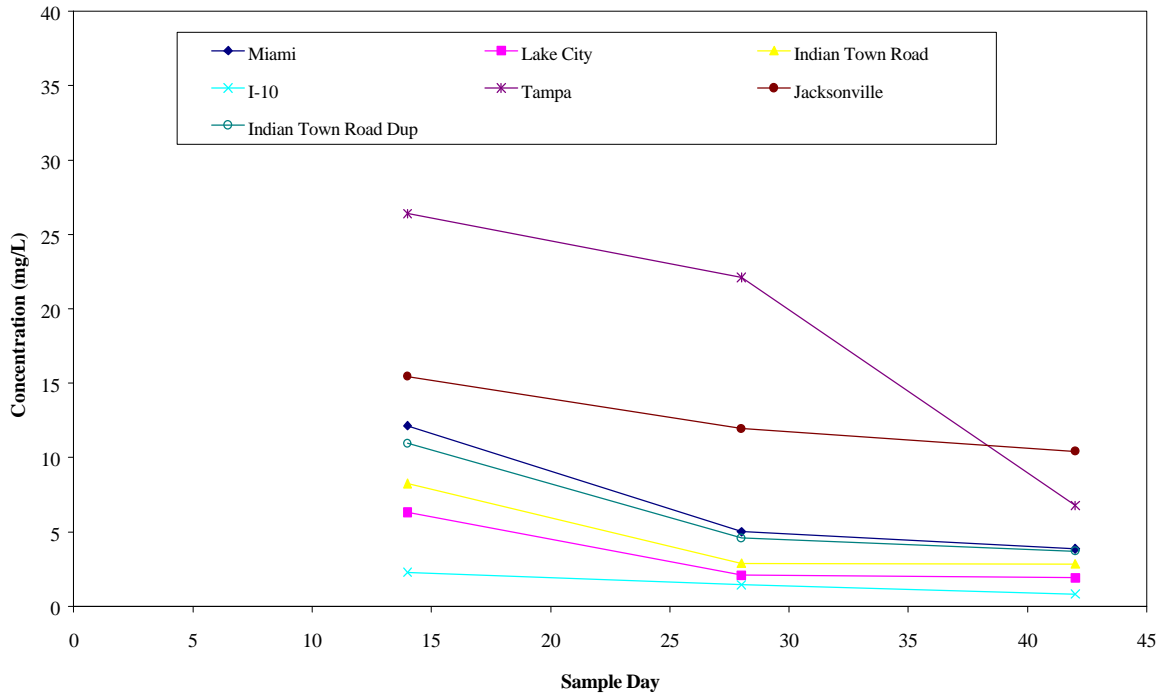


Figure 4.28 Saturated Sodium vs. Time

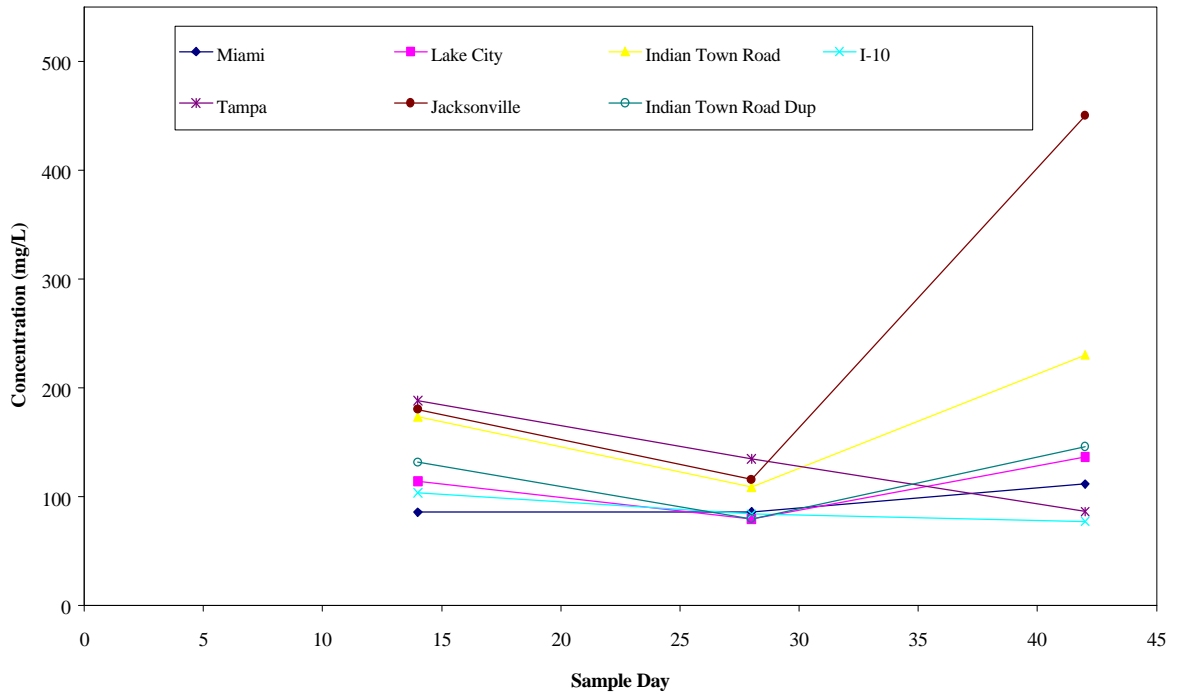


Figure 4.29 Saturated Calcium vs. Time

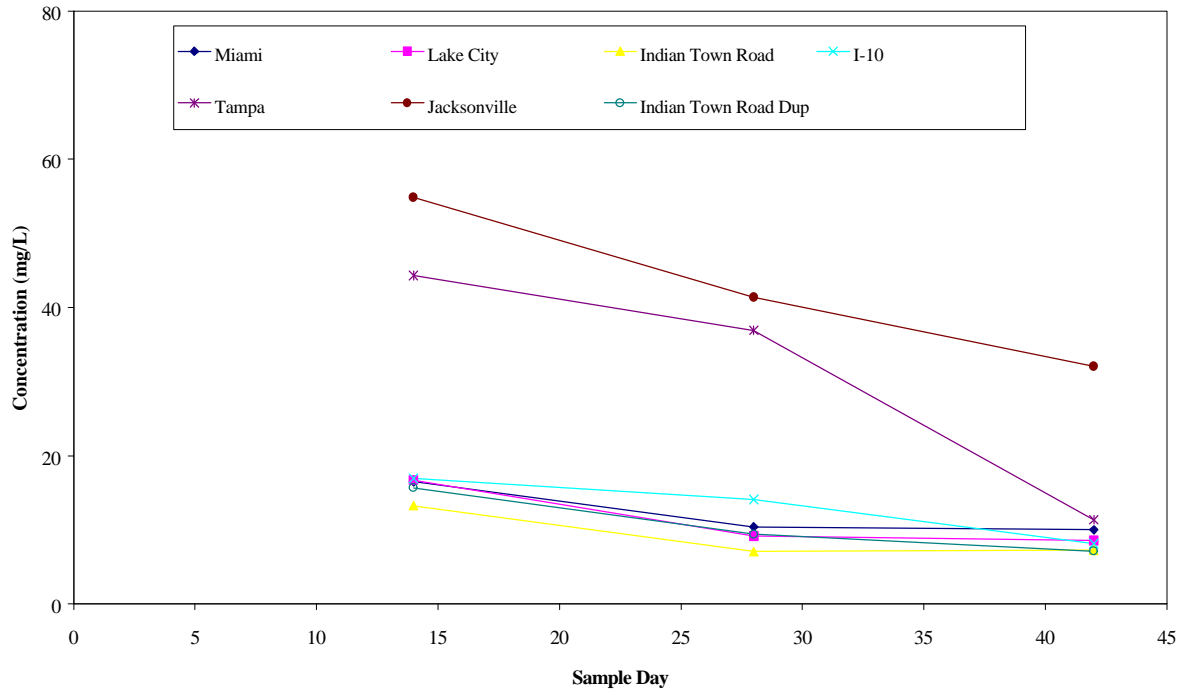


Figure 4.30 Saturated Magnesium vs. Time

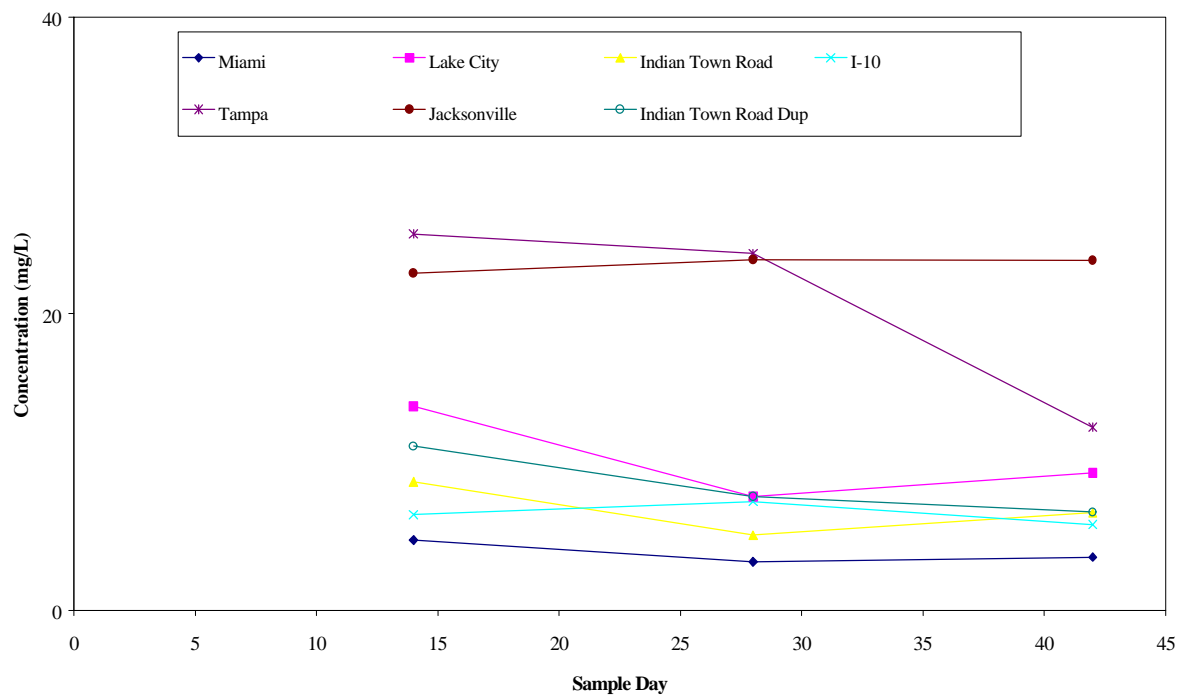


Figure 4.31 Saturated Potassium vs. Time

In the unsaturated and saturated columns, fluoride and chloride were detected in low concentrations. It is interesting to note that the Tampa samples had greater amounts of fluoride detected than all other samples. Fluoride must have been a larger component of the mineral aggregate. Small amounts of nitrate were detected in both column studies and remained constant throughout the study. Nitrate concentrations were similar to the control blank and DI blanks. Sulfate was detected in the unsaturated columns and leached following a typical leaching curve. The highest sulfate concentrations reached were approximately 550 mg/L but declined to a concentration around 50 mg/L. Sulfate was likely a mineral component of the aggregate. The saturated columns also followed this same pattern for sulfate. This ion was expected to be present in small amounts due to the nature of the leaching solution.

For both column conditions, all cations tested displayed the typical leaching curve. Sodium is typically found in Florida aggregates due to the increased amounts of NaCl in Florida and was expected to be present. Calcium was also expected to be present due to the type of aggregate used in HMA production. Typically, the aggregate used in the state of Florida is limerock (CaCO_3). Calcium was detected and followed the typical leaching trend. Towards the end of analysis, there was a slight increase in Ca^{+2} ions. This was contributed to a changed flow pattern in the columns. Magnesium is another ion usually found in Florida aggregate. Magnesium was detected in both column studies and followed a typical leaching trend. In the unsaturated columns, magnesium followed the same trend as calcium as well as potassium. These slight increases at the end of analysis were attributed to a changed flow pattern.

4.3.3 Volatile Organic Compounds (VOCs)

As mentioned earlier, VOCs were not expected to be a major concern in regard to leaching from RAP. Because of their volatility, most of these compounds would tend to evaporate quickly when spilled on the roadway or be expected to leave the RAP samples in the field.

Samples were taken directly from the columns and analyzed on a GC/MS. The results for all samples analyzed were below detection limit (BDL) of 1 ppb and never went above any regulatory guidelines. Appendix B has a detailed description of all samples analyzed and compounds of interest. It also includes QA/QC data for these samples.

4.3.4 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs were one of the major concerns related to this project. PAHs are generally formed during the incomplete combustion of coal, oil, or gas, but are found in other sources including vehicle exhaust, tire particles, and weathered material from asphalt roads.

Sixteen priority pollutant PAHs were analyzed for in the leachate samples collected from the lysimeters. The results for all samples analyzed were below detection limit (BDL) and thus were never above any regulatory guidelines. As discussed earlier, the detection limit for Benzo(A)pyrene had to be lowered accordingly. A list of the twelve samples used in that additional work is provided in Appendix A. Appendix B has a detailed description of all samples analyzed and compounds of interest. It also includes QA/QC data for these samples.

4.3.5 Heavy Metals

The other major compounds of interest were heavy metals. Heavy metals are often cited as a concern when dealing with materials from roadways. In the case of lead, it has been well documented that vehicular emissions have caused contamination to roadside soils (Harrison and Wilson, 1985a). The heavy metals selected for analysis are listed in Table 4.9.

Table 4.9 Heavy Metals

Target Compounds	Detection Limit (mg/L)	GW Guidance Concentration (mg/L)	Result
Barium	0.5	2	BDL
Cadmium	.005	.005	BDL
Chromium	0.1	0.1	BDL
Copper	0.5	1	BDL
Lead	.010	.015	****
Nickel	0.1	0.1	BDL
Zinc	0.5	5	BDL

Note: **** Pb will be discussed in greater detail

All metals analyzed for were below detection limit (BDL) (except for lead) and were thus below ground water guidance concentrations. The results for lead concentrations ($\mu\text{g/L}$) measured in the lysimeter leachate and the regulatory guidelines are listed in Table 4.10. Appendix B has a detailed description of all samples analyzed and compounds of interest. It also includes QA/QC data for these samples.

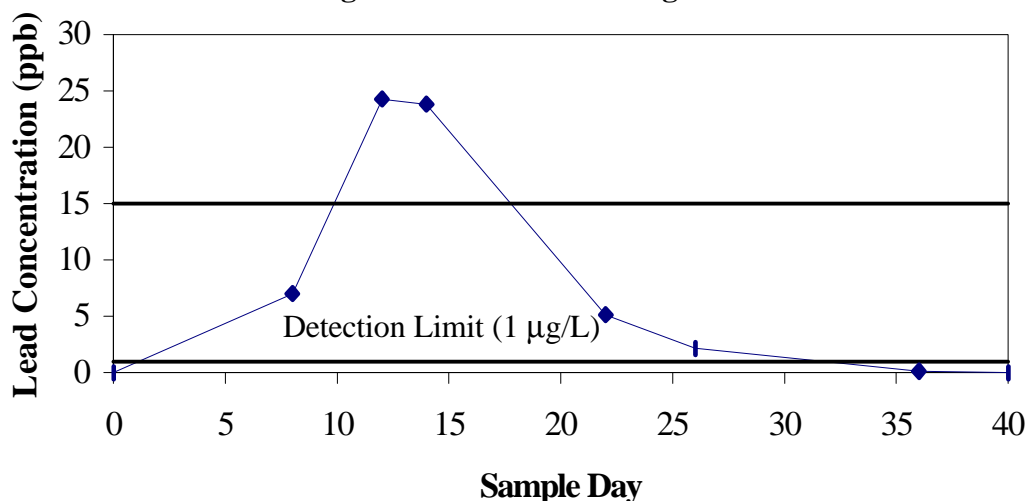
Table 4.10 Lead Results ($\mu\text{g/L}$)

Sample Day	Miami	Lake City	Indian Town Road	I-10	Tampa	Jacksonville	Indian Town Road Dup	Control Blank
Unsaturated Columns								
Day 8	BDL	BDL	BDL	BDL	BDL	7.00	BDL	BDL
Day 12	BDL	1.00	BDL	3.51	5.04	24.28	BDL	BDL
Day 14	BDL	1.64	BDL	3.72	5.80	22.87	BDL	BDL
Day 22	BDL	2.79	BDL	BDL	3.80	5.35	BDL	BDL
Day 26	BDL	BDL	BDL	BDL	1.17	2.29	BDL	BDL
Day 36	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Day 40	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Saturated Columns								
Day 14	10.38	5.25	38.27	12.7	5.60	26.5	33.4	-
Day 28	BDL	BDL	7.69	BDL	2.90	25	4.48	-
Day 42	BDL	BDL	BDL	BDL	BDL	18.7	BDL	-

The groundwater guidance concentration for lead is $15 \mu\text{g/L}$ and the detection limit used for lead analysis for the columns was $1 \mu\text{g/L}$. In the unsaturated columns, lead was detected above the guidance concentration in only the Jacksonville sample. In the saturated columns, lead was detected above the guidance concentration in three out of the six samples while trace amounts were detected in the other three. The leaching curve for the amount of lead detected in the Jacksonville site followed a typical leaching pattern. Figure 4.32 illustrates

the leaching trend in the unsaturated Jacksonville sample. The amount of lead leached off the RAP material increased initially and at around 20 to 25 days started to decrease down to BDL.

Figure 4.32 Lead Leaching Curve



The fact that lead was observed in the column and not in the batch test was a result of the dilution associated with each test. The batch tests used a 20 to 1 ratio of leaching solution to waste material. The ratios used in the column tests reported here were 0.257-to-1 for saturated conditions and 0.0367-to-1 for unsaturated conditions. When waste is applied in the environment, dilution and attenuation of chemicals in the leachate occur in most scenarios. Batch tests are typically compared to groundwater standards directly because a degree of dilution is already incorporated. With column tests, a dilution attenuation factor is typically applied to leachate concentrations to more accurately gage the impact of the waste material on groundwater quality.

The initial period of increase may be explained by the time needed to "wet" the RAP. The initial leachate samples consisted largely of fluid that, for the most part, washed through the column with little contact time with the RAP. Only after the first few leaching solution additions did the leachate that had been in contact with RAP for extended periods start being flushed out. During this contact, minerals in the RAP aggregate and some lead partitioned into the leachate. The fact that asphalt is a hydrophobic materials may magnify this effect, as seen possibly in the lead leaching curve for the Jacksonville RAP sample (Figure 4.32).

The total mass (μg) of lead leached from the columns is presented in Table 4.11. It was shown that the saturated columns had more mass leached than did the unsaturated columns. The reason for this was available contact time between the leaching solution and RAP sample. The unsaturated columns had less than two days of contact time while the saturated columns had fourteen days of contact time. The increased contact time in the saturated columns allowed for more dissolution of lead in the columns.

Contact time was also involved in the amount of lead being leached. In the saturated columns, the entire RAP sample had complete contact with the leaching solution. In the unsaturated columns, one liter of leaching solution was introduced every two days. Since

asphalt is a material made to be impervious to water, the leaching solution introduced had minimal contact with the RAP relative to the saturated columns.

Table 4.11 Total Mass (μg) of Lead Leached in Columns.

	Miami	Lake City	Indian Town Road	I-10	Tampa	Jacksonville	Indian Town Road Dup.
Unsaturated	0	25.36	0	36.85	44.23	126.58	0
Saturated	72.66	36.75	321.72	88.90	59.50	491.40	265.16

The lead concentration was greatest in the Jacksonville RAP sample, which also corresponded to the oldest RAP sample as determined by the physical characteristics. As previously stated, the viscosity of RAP increases with age and the penetration decreases with age. Older roads tend to have more exposure to accidental spills and to the use of leaded gasoline from previous years. The total mass of lead leached from the saturated columns is plotted as a function of viscosity in Figure 4.33 and as a function of penetration in Figure 4.34. These results indicate that the older samples likely contained more lead as a result of longer exposure to vehicle traffic and emissions.

The Jacksonville site, which has the highest viscosity, had the highest concentration of lead. Even though this was an older road, there may have been other factors involved in why lead was detected. The Jacksonville sample came from a mixed source pile. This material could have come from a parking lot or a downtown road where stop and go traffic occurred. Highways with large amounts of stop-and-go traffic would also tend to have more exposure time to spills and leaks. The I-10 sample, which has the second highest viscosity, has a very low concentration of lead. Even though I-10 is an older highway, it is a main interstate with no stop-and-go traffic.

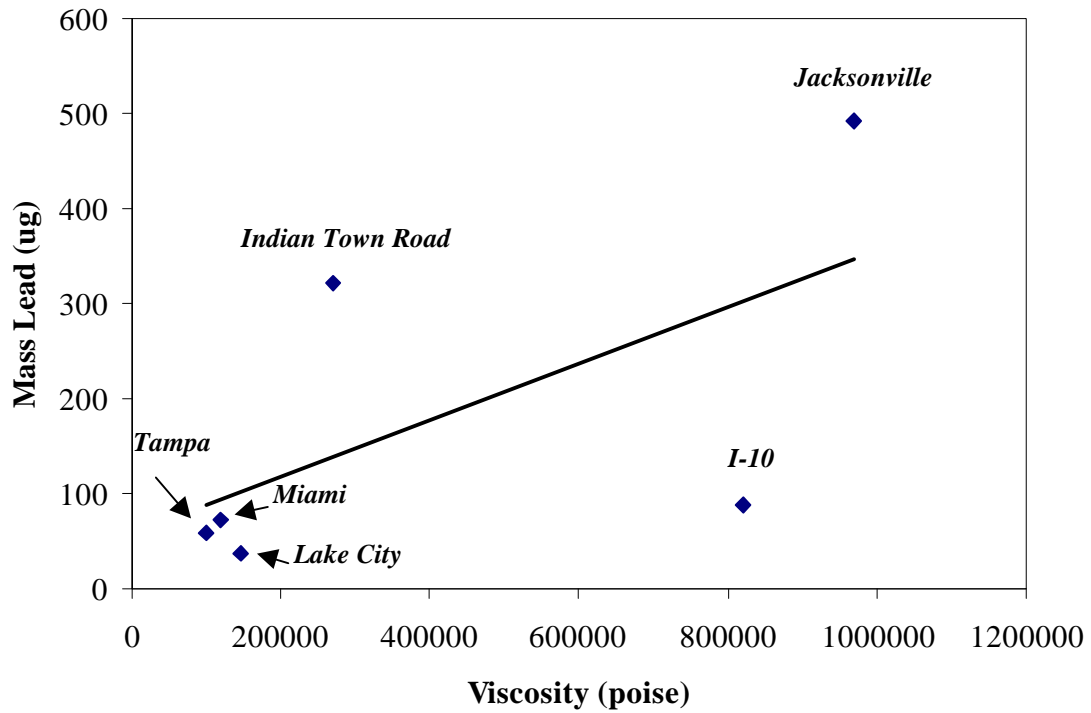


Figure 4.33 Viscosity vs. Total Lead (μg) Leached in Saturated Columns

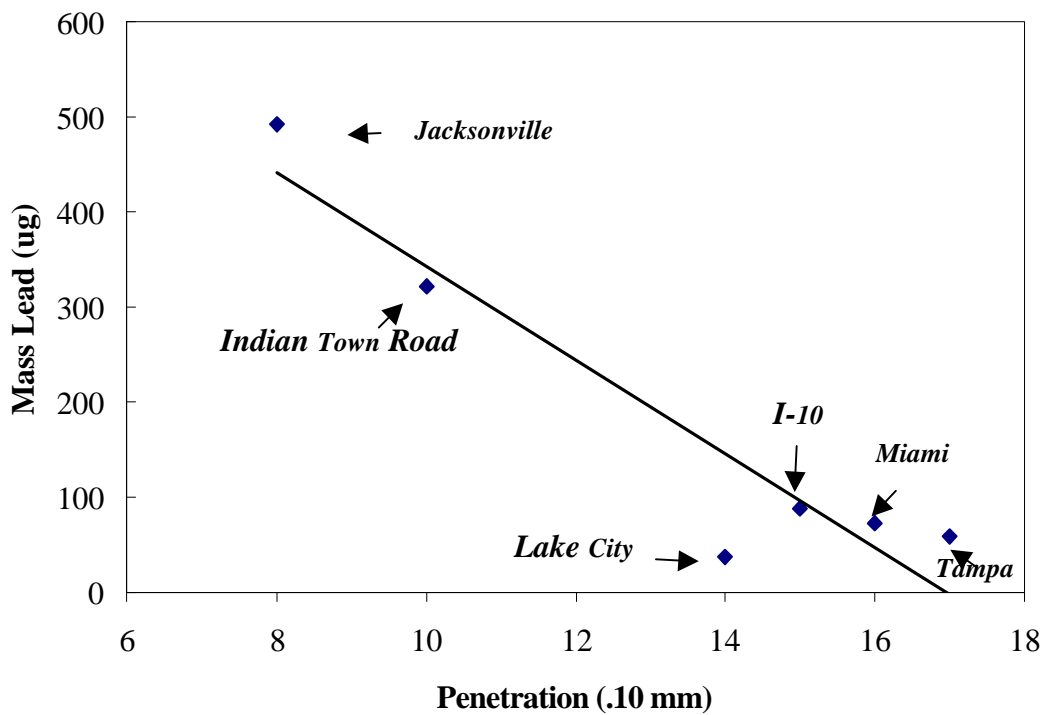


Figure 4.33 Penetration vs. Total Lead (μg) Leached in Saturated Columns

CHAPTER 5

CONCLUSIONS/RECOMMENDATIONS

Reclaimed asphalt pavement is a solid waste that in most cases can be directly recycled into new asphalt. Under some circumstances, recycling is not immediately possible, and the RAP may have to be stockpiled or managed in some other manner. This may include circumstances where the RAP is exposed to rainwater that could leach chemicals to the environment.

A series of batch tests and column studies were performed to evaluate the leaching characteristics of reclaimed asphalt pavement. Samples of RAP were collected from six sites in Florida. The batch tests performed consisted of the Toxicity Characteristic Leaching Procedure (TCLP), the Synthetic Precipitation Leaching Procedure (SPLP), and a deionized water test. The column study utilized 16 stainless steel columns (lysimeters) assembled at the University of Florida Solid and Hazardous Waste Lab.

Batch tests were performed on all six RAP samples. In leachate generated during the TCLP batch test, measurements of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and heavy metals all were below detection limit (BDL) and below any applicable TCLP limits. The RAP samples evaluated were therefore not hazardous waste. This result was expected, as the literature had demonstrated this.

Batch tests are also used by regulatory agencies to determine whether a waste presents a potential leaching threat to groundwater. Concentrations of pollutants from batch tests are usually compared directly to groundwater limits or guidance concentrations. TCLP test is sometimes used. The literature did present some TCLP results that were above appropriate groundwater limits for some heavy metals (Kriech 1990, 1991, 1992). The TCLP test is a more aggressive test and represents the conditions inside an anaerobic landfill. Less aggressive tests were therefore also conducted in this study (SPLP and deionized water). The SPLP is currently the method of choice for evaluating leaching from waste or contaminated soils in Florida.

In all of the batch tests, measurements of VOCs, PAHs, and selected heavy metals (Ba, Ca, Cr, Cu, Pb, Ni, and Zn) all were below detection limit (BDL) and were below applicable regulatory groundwater guidance concentrations. This indicates that the RAP samples tested posed minimal risk (in regard to leaching of the pollutants tested) under current waste policy in Florida. No comparisons can be made regarding the effectiveness of each test to leach pollutants because no pollutants were measured.

Column (lysimeter) tests were then performed on the same six RAP samples. Column tests are not a prescribed test procedure by regulatory agencies. They were conducted in this case to investigate leachate production from RAP under more realistic environmental scenarios. Approximately 60 lbs of RAP material filled a three foot section of each column. The RAP in these columns were subjected to either a saturated or unsaturated condition. Samples were analyzed for the same parameters as in the batch tests, but leaching was

continued for a total of 42 days. The columns did leach large concentrations of ions such as calcium, sodium, sulfate, fluoride, and carbonate as a result of mineral leaching from the aggregate used in the asphalt pavement manufacture. Some organic material was leached. However, all priority pollutant VOC and PAH analyses had results similar to the batch test -- none were detected. Leachate concentrations for selected heavy metals (Ba, Ca, Cr, Cu, Ni, and Zn) were below detection limit (BDL) except lead (Pb).

Only one unsaturated lysimeter resulted in a leachate with a lead concentration above the groundwater guidance concentration (15 ppb). Leachate from the unsaturated lysimeter containing the Jacksonville sample had a lead concentration of approximately 28 ppb eight days into the sampling period. The concentration of lead decreased over time and then leveled off below the regulatory guidance concentration. In the saturated columns, all columns had detectable concentrations of lead ranging from 5 ppb to 38 ppb. Three out of the six lysimeters (two sites) were above the regulatory guideline. The lysimeters decreased over time to lead concentrations below the guidance concentration (and the detection limit) except the Jacksonville sample. The Jacksonville sample concentration decreased slightly but was still above the guidance concentration at approximately 18 ppb.

As discussed previously, the batch tests were more dilute than the column test. This condition helps to explain why lead concentrations were observed in the column study but not in the batch test. In a real world situation, rainfall and other surface water runoff would ultimately dilute leachate produced from a stockpile before it reaches the groundwater table or a nearby receiving body of water. This phenomenon is commonly referred to as dilution attenuation. Dilution-attenuation models used to determine the concentration of groundwater underneath waste piles and landfills commonly apply a dilution factor of 20 (EPA, 1996). In batch tests, dilution is usually assumed to be accounted for because of the high liquid-to-solid ratio. In the column study there was no dilution-attenuation factor involved. If the concentrations produced from the column studies were placed into a groundwater dilution model, results would likely be well below any regulatory guideline. Under most reuse circumstances, even if lead was encountered at levels of the highest amount measured in this study, the concentrations in the environment would be below acceptable regulatory levels for drinking water. Possible conditions of risk would be from RAP used as fill below the groundwater table in areas with little dilution.

Lead was observed in the greatest concentrations in the oldest RAP samples. This indicated that the lead was not a result of the aggregate or asphalt cement, but rather a result of vehicle traffic and emissions. Lead has been used for many years in leaded gasoline and in crankcase oil. Since vehicle accidents and accidental spills contribute to this contamination, there is a possibility that this contamination was site specific. Previous studies regarding asphalt road waste also found trace amounts of lead in some circumstances (Kriech, 1991). Lead was encountered in greater concentrations in older samples, indicating that the source of lead was prolonged exposure to vehicle traffic and emissions.

Most of the previous studies reviewed in Chapter 2 regarding RAP leaching were consistent with the results found in this study. Organic compounds do not leach from typical RAP under the conditions tested. Heavy metals are sometimes encountered. The literature

indicated the presence of chromium, lead, and barium. Only lead was detected in this study and was attributed to prolonged exposure to traffic and vehicle emissions. The literature often referred to chromium resulting from slag used as aggregate. It should be noted that the aggregate used in the asphalt samples collected for this study was assumed to be natural aggregate (e.g. limerock). If other materials -- especially waste materials such as slag, spent sandblast grit and ash -- are used as aggregate, the results gathered here may not be applicable. It should also be noted that fresh asphalt was not tested, nor were extremes in temperatures evaluated.

The results of this research project indicated that reclaimed asphalt pavement of the nature examined in this study poses minimal risk to groundwater as a result of pollutant leaching under normal land disposal scenarios. The results of the leaching tests indicated that in most cases RAP would pose minimal environmental risk when used as fill in regard to the leaching of the pollutants. This study did not, however, address that implication of direct exposure.

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