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Evaluation of Wilder Construction Company's MatCon™ Cover Technology

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and ground water; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Hugh W. McKinnon, Director
National Risk Management Research Laboratory

Abstract

To enhance conventional paving asphalt to make it more suitable for containment applications, Wilder Construction Company of Everett, Washington, developed MatCon,™ a polymer modified asphalt system. The system is comprised of a proprietary binder, coupled with a selected aggregate type and gradation, and a specialized job mix formula. This system, when applied using installation specifications, results in a potentially superior substitution for conventional paving asphalt in cover containment applications. Under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program, the system was installed for evaluation at two locations, with another possible in 2003.

MatCon™ is intended for use as a waste containment material, to comprise a single or multiple layer cover system. MatCon™ is noted for its superior engineering qualities and is designed for long-term performance, yet can be applied with conventional paving equipment. The hydraulic performance of the material was examined by both removing destructive samples for laboratory testing, as well as field evaluation. While the study focuses on hydraulic properties, accompanying engineering properties were evaluated in the laboratory.

An important benefit of MatCon™ is the potential for multi-use as parking, storage of materials, and even recreational sites such as tennis courts, created by the more durable surface that does not need to be covered by soil or other protective materials. MatCon™ contributes to improved properties over conventional asphalt by rendering the binder less susceptible to deformation or rutting and less likely to crack in cold climates. The short-term results of this testing show that MatCon™ specimens were not adversely affected and conventional asphalt mixtures deteriorated over the 100-day test duration.

This is a long-term research effort, but preliminary results from both laboratory and field surface ponding tests show that the MatCon™ cover system yields hydraulic conductivity results that meet or exceed fundamental baseline targets for RCRA Subtitle C cover systems. Research will continue to assess performance over the long-term.

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Acronyms, Abbreviations, and Symbols

ASHTO	American Society of State Highway and Transportation Officials
AMRL	Asphalt Materials Reference Library
ARAR	Applicable or relevant and appropriate requirement
ASTM	American Society for Testing and Materials
cm/sec	Centimeters per second
COE	U.S. Army Corps of Engineers
CQC	Construction quality control
DAFB	Dover Air Force Base
DLS	Drainage layer sump
EPA	U.S. Environmental Protection Agency
HDPE	High-density polyethylene
ITER	Innovative Technology Evaluation Program
MPa	Megapascal
NRMRL	National Risk Management Research Laboratory
ORD	EPA Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PG	Performance grade
PRI	PRI Asphalt Technologies, Inc.
PVC	Polyvinyl chloride
QA	Quality assurance
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RPD	Relative percent difference
SARA	Superfund Amendments and Reauthorization Act of 1986
SITE	Superfund Innovative Technology Evaluation
TCL	Tri-County Landfill
TEP/QAPP	Technology Evaluation Plan/Quality Assurance Project Plan
TER	Technology Evaluation Report
UV	Ultraviolet
WCC	Wilder Construction Company
WMI	Waste Management, Inc.

Conversions

	To Convert From	To	Multiply By
Length	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
Mass:	pound	kilogram	0.454
Energy:	kilowatt-hour	megajoule	3.60
Power:	kilowatt	horsepower	1.34
Temperature:	(°Fahrenheit - 32)	°Celsius	0.556

Acknowledgments

This report was prepared under the direction of Mr. David Carson, the Environmental Protection Agency Superfund Innovative Technology Evaluation Program project manager at EPA's National Risk Management Resource Laboratory in Cincinnati, Ohio. Contributors and reviewers for this report were Dr. Ronald Terrel of Terrel Research in Edmonds, Washington; Mr. Karl Yost of Wilder Construction Company in Everett, Washington; and Kenneth Grzybowski of PRI Asphalt Technologies, Inc., in Tampa, Florida. Gregory Jackson of Dover Air Force Base and Mike Peterson of Waste Management, Inc., provided invaluable field support during the demonstrations.

Executive Summary

Hazardous waste has been contained at several Resource Conservation and Recovery Act (RCRA) and Superfund sites around the country for the past 20 years using clay and geosynthetic covers. These covers often do not allow site reuse for industrial or commercial development. With the growing need to redevelop Brownfields sites (contaminated sites in urban areas), covers that allow industrial or commercial use are preferred. Wilder Construction Company (WCC) of Everett, Washington, has developed the MatCon™ (Modified Asphalt Technology for Waste Containment) technology for covers, which allows site reuse at hazardous waste sites. In 1998, WCC requested the U.S. Environmental Protection Agency (EPA) to evaluate this technology under the Superfund Innovative Technology Evaluation (SITE) Program at Dover Air Force Base (DAFB) in Dover, Delaware. In 1999, the evaluation was expanded to also include the Tri-County Landfill (TCL) Superfund site in Elgin, Illinois. This Innovative Technology Evaluation Report (ITER) presents the details of the evaluation and the performance data obtained at the DAFB and TCL sites. The following sub-sections describe the sites and evaluation procedures, list objectives and summarize associated results, and provide conclusions.

Dover Air Force Base Site

The Matcon™ cover installed at the DAFB covered an area of 124 x 220 feet (ft). The installation was completed in April 1999, and samples were collected in August 1999. The Matcon™ cover at the DAFB site consisted of three, hydraulically independent sections; Section I was a 12-inch-thick section (one 4-inch-thick open graded MatCon™ layer serving as a drainage layer between two 4-inch-thick layers of MatCon™; Section II was a 4-inch-thick MatCon™ layer; and Section III was a 4-inch-thick layer of conventional asphalt. Perforated high density polyethylene (HDPE) pipes were placed in the open graded MatCon™ layer within Section I to convey water infiltrating the MatCon™ cover to a sump at the edge of the cover.

Several cores and slab samples of the MatCon™ and conventional asphalt covers were collected from this site to compare the following laboratory-measured properties of MatCon™ with conventional asphalt.

- Hydraulic permeability
- Flexural properties
- Joint integrity
- Load capacity
- Tensile strength
- Thermal crack resistence
- Permeability after 30 and 60 days of accelerated weathering
- Fuel resistance
- Void space
- Aggregate properties
- Hydraulic transmissivity of the drainage layer (open graded MatCon™)

In addition, field permeability was calculated by measuring the infiltration through the MatCon™ cover during precipitation events. Field permeability tests were performed on Section I at the DAFB site.

Tri-County Landfill Site

A 3.6-acre (14,569-square meter [m^2]) MatCon™ cover was installed at the TCL site in November 1999 adjacent to the recycling facilities of Waste Management, Inc. The thickness of the MatCon™ cover was 4 inches (10 cm) over most of the area except the lysimeter test section (30 feet by 80 feet [9.2 by 24.2 m]), which consisted of 2 inches (5 cm) of conventional asphalt overlain by 40-millimeter-thick geomembrane and geotextile, 6 inches (15 cm) of coarse aggregate, and 4 inches (10 cm) of MatCon™ cover. A 3-inch-diameter (7.6-cm) perforated HDPE drainage pipe was placed in the 6-inch-thick (15-cm) aggregate section to convey the infiltration into the MatCon™ cover to a sump at the edge of the cover. This variation in the drainage layer design from what was used at the DAFB site was requested by the U.S. Army Corps of Engineers, the supervisor of the remediation at the TCL site.

Laboratory samples were collected from locations away from the lysimeter test section. These samples were tested for void space, aggregate properties, and hydraulic permeability. In April 2000, further sampling was completed at an area of the cover where a crack was observed. WCC determined that the crack was due to a cold joint formed because of poor workmanship during the November installation (see Section 4.1.3.2). The crack was repaired, and a procedure for construction of cold joints was developed (Appendix B).

Field permeability was also calculated at the TCL site by measuring the infiltration through the MatCon™ cover during precipitation events and constant-exposure ponding tests. Field permeability tests were performed on the demonstration portion of the cover at this site.

Objectives and Results

The technology demonstration objectives and results are described below.

- Primary objective 1: Determine if the MatCon™ cover exhibits a field permeability of less than the RCRA Subtitle C requirement of 10^{-7} centimeters per second (cm/sec). At the DAFB site, the field permeability values of the MatCon™ cover varied from 1.28 x 10^{-7} cm/sec to 1.31 x 10^{-8} cm/sec. A 6-hour ponding test indicated a permeability of 1.25 x 10^{-8} cm/sec.

  At the TCL site, the field permeability of the MatCon™ cover varied from 3.36 x 10^{-9} cm/sec to 5.15 x 10^{-10} cm/sec based on drainage measurements during precipitation events. A 48-hour ponding test on the cover yielded a permeability value of 5.0 x 10^{-8} cm/sec.

- Primary objective 2: Compare the laboratory-measured permeability and flexural properties of the MatCon™ cover with the conventional asphalt cover at the DAFB site. At the DAFB site, the laboratory permeability of the MatCon™ cover was less than 1.0 x 10^{-8} cm/sec, whereas the permeability of conventional asphalt varied from 1.04 to 2.75 x 10^{-4} cm/sec. At the TCL site, the laboratory permeability of the MatCon™ cores was less than 1.0 x 10^{-8} cm/sec, except for the cores obtained on the crack described above, which had a permeability of 3.56 x 10^{-5} cm/sec. The cores obtained on the crack had a void content of 8.2 percent, compared to less than 3 percent for properly installed MatCon.™

  A 36-inch-long beam of MatCon™ asphalt sustained 20.41 millimeter (mm) of deflection without cracking, whereas a conventional asphalt beam cracked at 7 to 10 mm deflection. The conventional asphalt beam showed 3-mm wide, 2.5-cm long cracks at about 25 mm of deflection.

- Secondary objective 1: Compare other laboratory-measured physical properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site. The resilient modulus of the MatCon™ cover was 2,048 megapascals (Mpa), compared to 3,200 Mpa for the conventional asphalt cover at cold temperatures (-20 degrees C). This reduced modulus suggests that MatCon™ is more flexible and less susceptible to cracking at cold temperatures.

  The tensile strength of the MatCon™ cover was 3.551 Mpa, compared to 2.579 Mpa for the conventional asphalt cover. The fracture temperature of the MatCon™ cover was 4.3 degrees Celsius lower than the conventional asphalt cover.

  The MatCon™ cover had a 37 percent higher fracture strength than conventional asphalt.

  The accelerated aging tests indicated that the MatCon™ cover was essentially unaffected by exposure to ultraviolet light, maintaining the same PG rating after 60 days of aging, whereas the conventional asphalt binder lost both high and low temperature performance on exposure to ultraviolet light. However, the permeability of the MatCon™ cover increased by an average of two orders of magnitude after accelerated aging (2.2 x 10^{-6} cm/sec). The permeability of the conventional cover remained generally unchanged (3.15 x 10^{-4} cm/sec).

  Exposure to cyclic water sprays for 60 days had a minimal effect on the binder properties of the MatCon™ cover, and the MatCon™ binder had wider performance grade as compared to the conventional asphalt binder.

Exposure to fuel degraded the top 1.5 cm (out of a total of 10-cm thickness) of the MatCon,™ cover, whereas the conventional asphalt cover showed 5.5 cm degradation (out of a total of 10-cm thickness).

- Secondary objective 2: Determine whether extreme weather conditions or vehicle loads affect the field performance of the MatCon™ cover. The MatCon™ surface performed well under extreme cold weather conditions and significant vehicle loads at the Tri-County Landfill site. The MatCon™ surface was used for parking recycling vehicles and garbage trucks from the day the cover was installed.

- Secondary objective 3: Estimate a cumulative hydrologic balance for the MatCon™ cover over the period of the demonstration at the DAFB site. A hydrologic balance could not be performed at the DAFB site.

- Secondary objective 4: Estimate the cost for constructing the MatCon™ cover and maintaining the cover for the duration of the demonstration. The cost of MatCon™ cover installation is estimated to be $124,000 to $140,000 per acre including subgrade preparations. This is comparable to the cost of RCRA Subtitle D covers and less than the cost per acre of RCRA Subtitle C covers, which range from $150,000 to $300,000, depending on the local availability of appropriate cover materials (Dwyer 1998).

Conclusions

The demonstrations at the DAFB and TCL sites indicate that the MatCon™ cover is suitable for use as a low permeability cover at hazardous waste sites. Based on the results of the test plots, the permeability of the MatCon™ cover was lower than or equal to the 1.0 x 10^{-7} cm/sec requirement for hazardous waste landfill covers. The demonstrated MatCon™ covers performed well under extreme cold weather conditions and under use as a staging area for heavy vehicles.

The MatCon™ cover permits site reuse. The main limitations of the technology are that it cannot be used at sites having slopes greater than 3 to 1 or at sites that cannot provide a firm and unyielding subgrade to support the paving equipment used to install the cover.

Section 1
Introduction

This section briefly describes the SITE Program and SITE reports; states the purpose and organization of this ITER; provides background information regarding the development of the MatCon™ process technology; identifies wastes to which this technology may be applied; and provides a list of key contacts who can supply information about the technology and demonstration site.

1.1 Description of SITE Program and Reports

This section briefly describes the purpose, history, and goals of the SITE Program, and the reports that document SITE demonstration results.

1.1.1 Purpose, History, and Goals of the SITE Program

The primary purpose of the SITE Program is to advance the development and demonstration, and thereby establish the commercial availability, of innovative treatment technologies applicable to Superfund and other hazardous waste sites. The SITE Program was established by the EPA Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA), which recognized the need for an alternative or innovative treatment technology research and demonstration program. The SITE Program is administered by ORD's National Risk Management Resource Laboratory (NRMRL). The overall goal of the SITE Program is to carry out a program of research, evaluation, testing, development, and demonstration of alternative or innovative treatment technologies that may be used in response actions to achieve long-term protection of human health and welfare and the environment.

The SITE Program includes the following elements:

- The MMT Program evaluates innovative technologies that sample, detect, monitor, or measure hazardous and toxic substances. These technologies are expected to provide better, faster, or more cost-effective methods for producing real-time data during site characterization and remediation studies than do conventional technologies.
- The Remediation Technology Program conducts demonstrations of innovative treatment technologies to provide reliable performance, cost, and applicability data for site cleanups.
- The Technology Transfer Program provides and disseminates technical information in the form of updates, brochures, and other publications that promote the SITE Program and participating technologies. The Technology Transfer Program also offers technical assistance, training, and workshops to support the technologies. A significant number of these activities are performed by EPA's Technology Innovation Office.

Innovative technologies chosen for a SITE demonstration must be pilot- or full-scale applications and must offer some advantage over conventional technologies. To produce useful and reliable data, demonstrations are conducted at actual hazardous waste sites or under conditions that closely simulate actual waste site conditions.

Data collected during the demonstration are used to assess the performance of the technology, the potential need for pretreatment and post-treatment processing of the treated waste, the types of wastes and media that can be treated by the technology, potential treatment system operating problems, and approximate capital and operating costs. Demonstration data can also provide insight into a technology's long-term operation and maintenance (O&M) costs and long-term application risks.

Under each SITE demonstration, a technology's performance in treating an individual waste at a particular site is evaluated. Successful demonstration of a technology at one site does not ensure its successes at other sites. Data obtained from the demonstration may require extrapolation to estimate a range of operating conditions over which the technology performs satisfactorily. Any extrapolation of demonstration data also should be based on other information about the technology, such as case study information.

Cooperative arrangements between EPA, the site owner, and the technology developer establish responsibilities for conducting the demonstration and evaluating the technology. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control (QA/QC), preparing reports, and disseminating information. The site owner is responsible for transporting and disposing of treated waste materials and site logistics. The technology developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operations, and removal of equipment.

Implementation of the SITE Program is a significant, ongoing effort involving ORD, OSWER, various EPA regions, and private business concerns, including technology developers and parties responsible for site remediation. The technology selection process and the Demonstration Program together provide a means to perform objective and carefully controlled testing of field-ready technologies. Each year, the SITE Program sponsors about 10 technology demonstrations. This ITER was prepared under the SITE Demonstration Program.

1.1.2 Documentation of Site Demonstration Results

The results of each SITE demonstration are usually reported in four documents: (1) a Demonstration Bulletin, (2) a Technology Capsule, (3) a Technology Evaluation Report (TER), and (4) the ITER. The Demonstration Bulletin provides a two-page description of the technology and project history, notification that the demonstration was completed, and highlights of the demonstration results. The Technology Capsule provides a brief description of the project and an overview of the demonstration results and conclusions.

The purpose of the TER is to consolidate all information and records acquired during the demonstration. The TER data tables and graphs summarize test results in terms of whether project objectives and applicable or relevant and appropriate requirements (ARAR) were met. The tables also summarize QA/QC data in comparison to data quality objectives. The TER is not formally published by EPA. Instead, a copy is retained by the EPA project manager as a reference for responding to public inquiries and for record-keeping purposes. The purpose and organization of the ITER are discussed in Section 1.2.

1.2 Purpose and Organization of the ITER

Information presented in the ITER is intended to assist decision-makers in evaluating specific technologies for a particular cleanup situation. The ITER represents a critical step in the development and commercialization of a technology demonstrated under the SITE Program. The ITER discusses the effectiveness and applicability of the technology and analyses costs associated with its application. The technology's effectiveness is evaluated based on data collected during the SITE demonstration and from other case studies. The applicability of the technology is discussed in terms of waste and site characteristics that could affect technology performance, material handling requirements, technology limitations, and other factors.

This ITER consists of six sections, including this introduction. Sections 2 through 6 and their contents are summarized below.

- Section 2, Treatment Applications Analysis, discusses information relevant to the application of the MatCon™ process technology, including an assessment of the technology related to the nine feasibility study evaluation criteria, potentially applicable environmental regulations, and the operability and limitations of the technology.
- Section 3, Economic Analysis, summarizes the actual costs, by cost category, associated with using the MatCon™ process technology, variables that may affect costs at other sites, and conclusions derived from the economic analysis.
- Section 4, Technology Effectiveness, presents information relevant to the design and implementation of the technology. It also presents an overview of the SITE demonstration objectives, documents the demonstration procedures, and summarizes the results and conclusions of the demonstration.
- Section 5, Technology Status, summarizes the developmental status of the MatCon™ process technology.
- Section 6, References, lists the references used to prepare this ITER.

In addition to these sections, this ITER has two appendices: Appendix A, Vendor's Claims for the Technology and Appendix B, Vendor's Discussion of MatCon™ Cold Joints.

1.3 Matcon™ Technology Description

MatCon™, an abbreviation for Modified Asphalt Technology for Waste Containment, is a technology developed by Wilder Construction Company (WCC) to contain hazardous wastes at RCRA and Superfund sites. The MatCon™ asphalt mix contains high quality, specifically sized mineral aggregate and a highly modified proprietary binder using additives beneficial to environmental applications. The binder content is about 7 percent, and the air void content is less than 3 percent compared to an air void content of about 8 percent for conventional asphalt mixes.

The MatCon™ mix, when properly installed using high quality paving techniques, offers unique advantages over conventional asphalt. The permeability of MatCon™ is less than 10^{-7} cm/sec, and it offers greater resilience and longevity than conventional asphalt. The first MatCon™ cover was installed in Ferndale, Washington in 1989.

The advantages claimed by WCC for the MatCon™ technology include the following.

- MatCon™ does not crack like compacted clay and is not subject to damage under ultraviolet light exposure
- MatCon™ resists corrosion and conforms well to small differential settlement of underlying materials
- MatCon™ cover thicknesses vary from 4 to 12 inches (10 to 30.5 cm) compared to conventional RCRA covers, which are over 3 feet (0.9 meter) thick
- MatCon™ can be rapidly installed on a prepared subgrade (about 1.5 acres per day [0.6 hectares per day]) and used immediately after installation
- A large number of asphalt paving contractors in the country have the skill, equipment, and trained personnel to install MatCon™ according to WCC specifications

During a typical MatCon™ cover installation, WCC brings its proprietary binder to a local asphalt plant and provides supervision for hot mix preparation. The MatCon™ asphalt mix is then placed as a cover under strict assurance QC specifications provided by WCC. A 4-inch thick (10-cm), highly permeable (about 1 x 10^{-2} cm/sec) drainage layer made of open graded MatCon™ is sandwiched between two 4-inch thick (10-cm) layers of impermeable MatCon™ mix to create a double lined version of the system.

1.4 Key Contacts

Additional information on the MatCon™ cover technology is available from the following sources.

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Gregory D. Jackson, P.E. (DAFB site contact)
Environmental Engineer
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600 Chevron Avenue
Dover Air Force Base, DE 19902-6600
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FAX: (302) 677-6837
email: gregory.jackson@dover.af.mil

Michael Peterson (TCL site contact)
Waste Management, Inc.
West 124 North 9355 Boundary Rd.
Menominee Falls, WI 53051
Telephone: (262) 253-8626, ext. 115
FAX: (262) 255-3798
email: mpeterson@wastemanagement.com

Section 2
Technology Applications Analysis

This section describes the SITE demonstration objectives and evaluation design conclusions, including the demonstration results, factors influencing the effectiveness of the MatCon™ technology, personnel requirements, potential regulatory requirements, and appropriate waste and site conditions. The vendor's claims regarding the applicability and performance of the technology are included in Appendix A. The technology's applicability is based on the results of two demonstrations conducted under the SITE Program. The SITE demonstration results are presented in detail in the TER.

2.1 SITE Demonstration Objectives and Conclusions

The SITE demonstrations were conducted at DAFB in Dover, Delaware (Figure 2-1) and TCL in Elgin, Illinois (Figures 2-2 and 2-3), where contaminated site capping was in progress. WCC (1998) provides details of WCC's demonstration program application for the DAFB site. The objectives of the two demonstrations are described below.

Each of the project objectives is listed below and identified as either primary (P) or secondary (S). Primary objectives were considered critical for the technology evaluation, and secondary objectives provided additional useful information. For each objective, a brief description of the experimental approach is given. Details of the experimental approach and results are given in Section 4.0.

Two primary objectives were identified:

P1--Determine if the MatCon™ cover exhibits a field permeability of less than the RCRA Subtitle C requirement of 10^{-7} centimeters per second (cm/sec) (CFR, 2002).

To estimate the field permeability of the MatCon™ cover, the volume of infiltration during individual rainfall events was measured during the demonstration period at each of the two sites.

Using Darcy's Law, the measured infiltration rates were converted into estimates of field permeability, and these estimates were compared to the regulatory requirement. Field permeability was calculated as the hydraulic conductivity of the installed cover, and reported in the units cm/sec. Although the terms permeabilityand hydraulic conductivity are typically defined separately, the terms are considered to be interchangeable for the purpose of discussion of this demonstration.

P2--Compare the laboratory-measured permeability and flexural properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site.

The vendor claims that the MatCon™ cover is less permeable and has superior flexural properties when compared to conventional asphalt. To test these claims, laboratory tests that evaluate the two properties were conducted on both MatCon™ and conventional asphalt samples from the DAFB site. Results for each parameter were then compared to determine whether the MatCon™ cover appears to be superior to conventional asphalt for these two critical parameters.

Four secondary objectives were identified:

S1--Compare other laboratory-measured physical properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site.

The vendor makes no specific claim for the superiority of MatCon™ to conventional asphalt with respect to physical parameters, other than permeability and flexural properties. However, differences in other physical properties that can be measured in the laboratory may be of interest to potential users. Therefore, samples of both

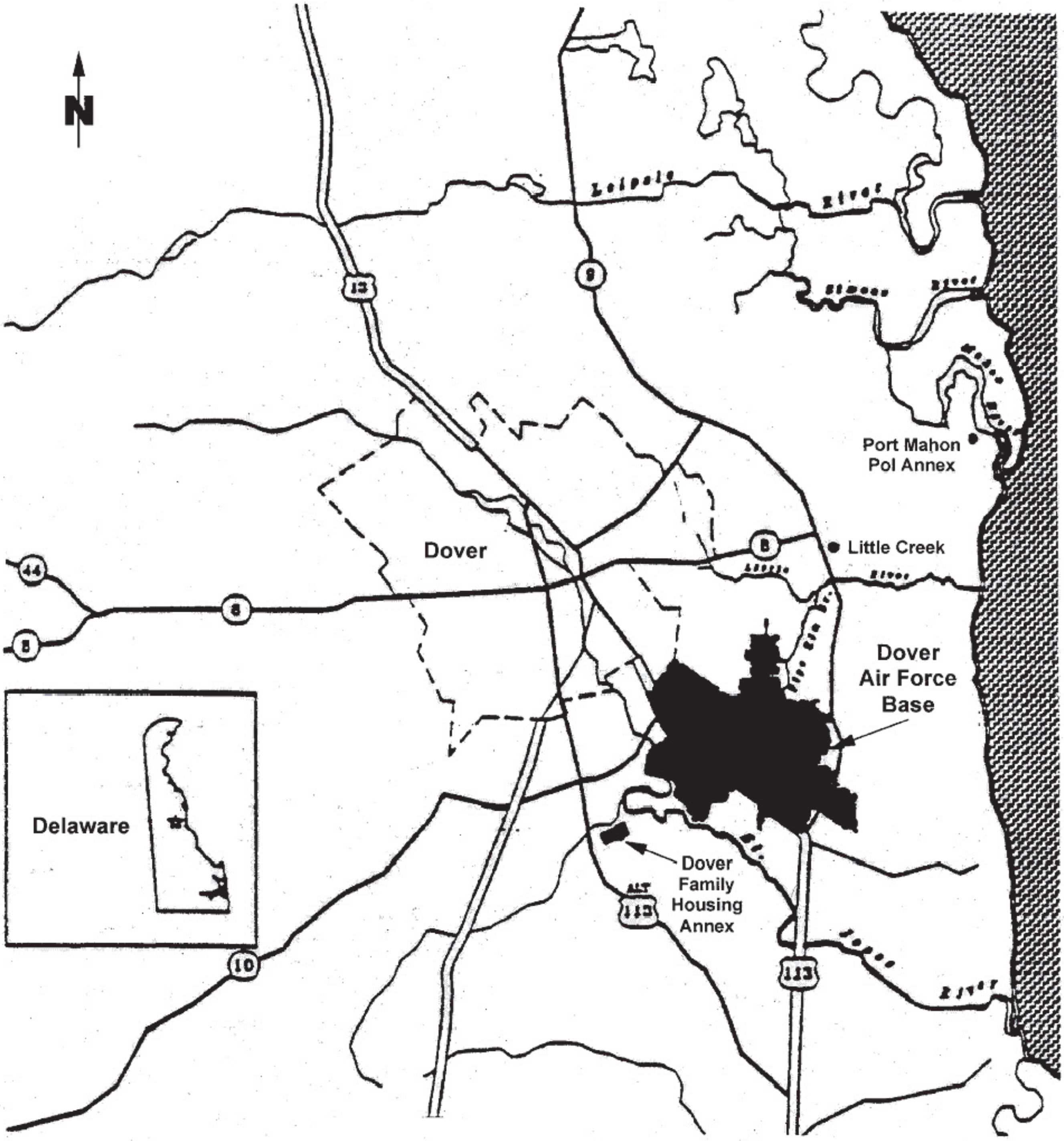

Figure 2-1. Location of Dover Air Force Base.

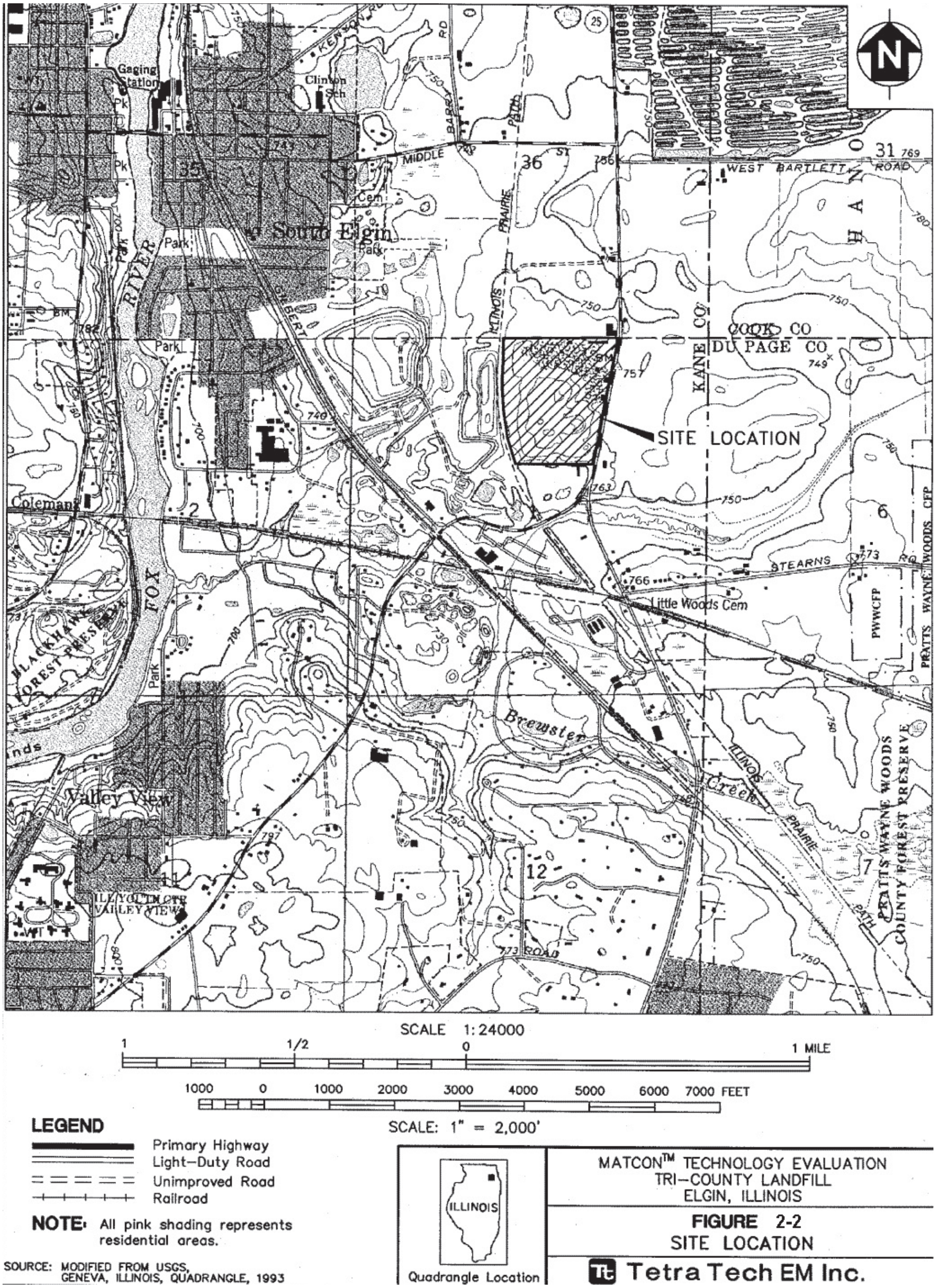

Figure 2-2. Site location, Tri-County Landfill, Elgin, Illinois.

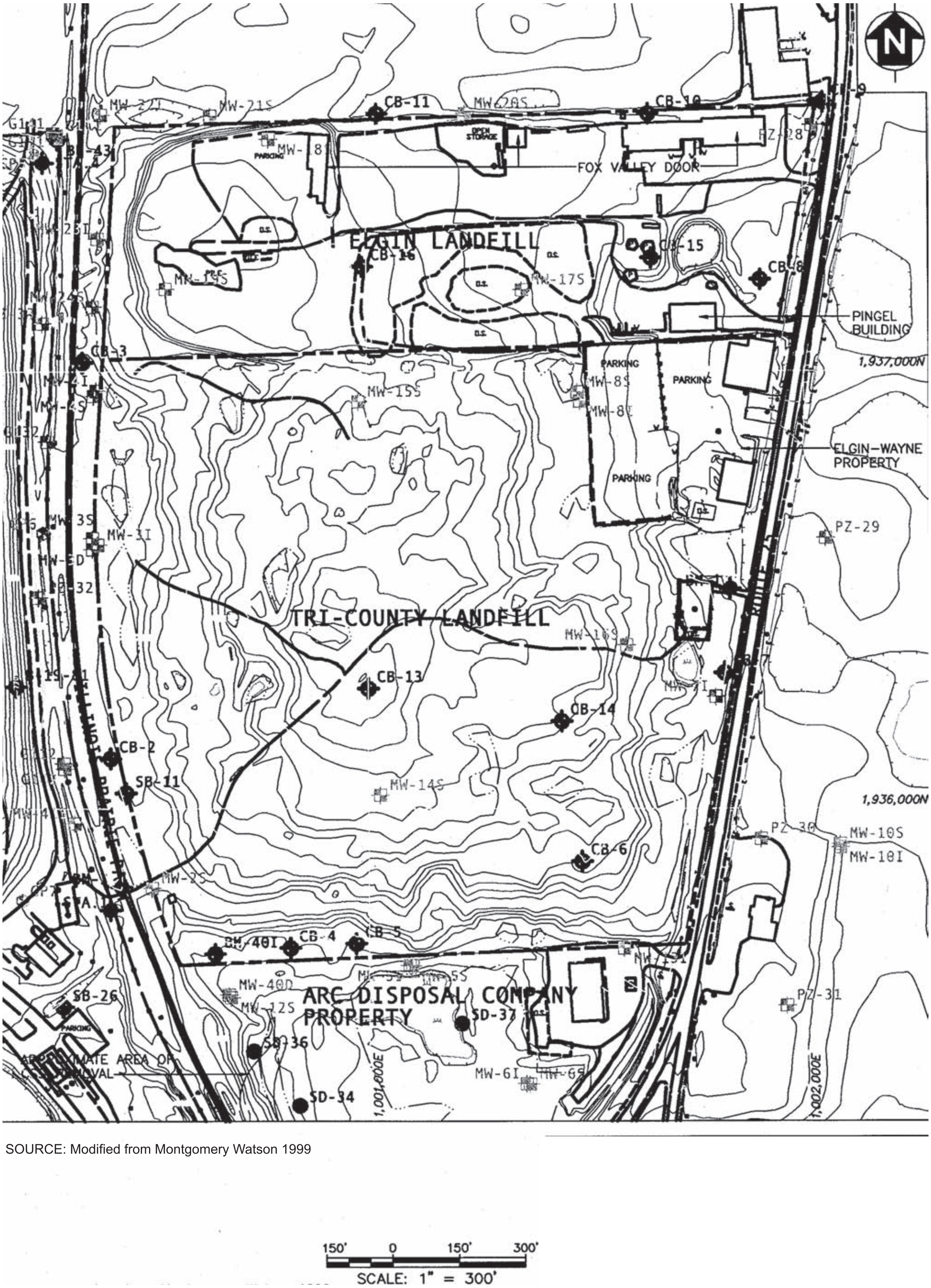

Figure 2-3. Site layout, Tri-County Landfill, Elgin, Illinois.

the MatCon™ cover and the conventional cover were collected from the DAFB site and analyzed for various parameters pertinent to the physical performance of the cover. Results for each parameter were then compared to determine potential significant differences between the two types of covers.

S2--Determine whether extreme weather conditions or vehicle loads affect the field performance of the MatCon™ cover.

To evaluate this objective, the MatCon™ covers at both sites were inspected periodically in the field, particularly following periods of extreme cold or other adverse weather conditions, to assess the development of potential cracks or surface defects. These field inspections were used to evaluate the effects of extreme weather or vehicle loads since the previous inspection. General information on use of the covers and on recent weather events was collected from the site owners and evaluated against any surface defects noted in the field inspections. The TCL site in Elgin, Illinois encountered much colder temperatures than the DAFB site in Dover, Delaware. As a result, data on the impacts of extreme cold were observed only at the TCL site.

S3--Estimate a cumulative hydrologic balance for the MatCon™ cover over the period of the demonstration at the DAFB site.

A hydrologic balance for the cover system was estimated at the DAFB site. The hydrologic balance was based on cumulative precipitation, totalized surface runoff, and subsurface drainage during the demonstration period.

S4--Estimate the cost for constructing the MatCon™ cover and maintaining the cover for the duration of the demonstration.

The capital and operating costs for the MatCon™ cover technology, as demonstrated at both the DAFB and TCL sites, were estimated based on the following 12 cost categories: site and facility preparation cost; permitting and regulatory costs; equipment costs; labor costs; consumables and supplies costs; startup and fixed costs; utilities costs; effluent treatment and disposal costs; residual and waste shipping, handling, and transportation costs; analytical costs; facility modification, repair, and replacement costs; and site restoration costs. Cost information obtained from WCC was reviewed by Tetra Tech in preparing the cost estimate.

2.2 Feasibility Study Evaluation Criteria

The MatCon™ technology performance demonstrated at the DAFB and TCL sites satisfied the nine criteria used for determining its feasibility for Superfund sites. Table 2-1 summarizes the performance of the technology with respect to each of the nine feasibility criteria for application at Superfund sites. Further analysis of MatCon™ performance is provided in the following sections.

2.2.1 Overall Protection of Human Health and the Environment

Hazardous waste landfills may adversely impact human health and the environment by producing airborne contamination and hazardous leachate. The MatCon™ cover provides complete containment of the hazardous waste and limits these adverse impacts. It has been successfully implemented at the DAFB and TCL sites and at McClelland Air Force Base in California.

2.2.2 Compliance with Applicable or Relevant and Approriate Requirements

The primary ARAR for source control at hazardous waste landfills is the RCRA Subtitle C permeability requirement of 10^{-7} cm/sec for hazardous waste landfills. The demonstrations at the DAFB and TCL sites have shown that the permeability of the MatCon™ cover is less than 10^{-7} cm/sec. Therefore, the MatCon™ technology satisfies the ARARs for hazardous waste landfills.

2.2.3 Long-Term Effectiveness and Permanence

Testing of various physical properties, such as fracture strength and resistance to accelerated weathering, has indicated that the MatCon™ cover is more durable than conventional asphalt, and can be a permanent containment system requiring limited maintenance. WCC installed the first MatCon™ cover over incinerator ash in Ferndale, Washington in 1989. This site was not evaluated as part of this demonstration; however, WCC claims that this cover has maintained a 10^{-8} cm/sec permeability over the past 12 years, even though the cover has been used as an active work surface for heavy equipment operation and material staging. The cover has required little or no maintenance over this long period, demonstrating the long-term effectiveness of the MatCon™ cover. The MatCon™ mix is made of natural and recyclable materials (aggregates and modified asphalt) that are used extensively in the

Table 2-1. Superfund Feasibility Evaluation Criteria for the MatCon™ Technology

Criterion	Discussion
Overall protection of human health and the environment	1. The MatCon™ technology is expected to protect human health by containing the hazardous waste. It affords environmental protection by preventing the formation of leachate at hazardous waste landfills.
Compliance with applicable or relevant and appropriate requirements (ARAR)	2. The MatCon™ technology complies with the RCRA Subtitle C permeability requirement of 10-7 cm/sec for hazardous waste landfill covers. It also complies with state and local ARARs.
Long-term effectiveness and permanence	3. Testing of various physical properties, such as fracture strength and resistance to accelerated weathering, has indicated that the MatCon™ cover can be a permanent containment system requiring limited maintenance. The technology uses natural and recyclable materials (aggregates and modified asphalt) that are used extensively in the construction industry.
Reduction of toxicity, mobility, or volume through treatment	4. The technology reduces the mobility of hazardous waste by reducing infiltration at landfill sites and does not involve waste treatment; therefore, this criterion is satisfied.
Short-term effectiveness	5. A MatCon™ cover can be constructed within a few weeks and can reduce infiltration immediately following installation. The technology can be implemented expeditiously and is effective in preventing water infiltration into the waste.
Implementability	6. The technology is readily implementable since hot mix plants are available in all parts of the country. Standard, readily available paving equipment can be used
Cost	7. The cost is often less than RCRA Subtitle C clay and geosynthetic covers. Potential beneficial reuse of the site is a very attractive feature of the technology.
State acceptance	8. The technology has been approved in several states, including Delaware, Illinois, Texas, California, Florida, Washington, and others because of the redevelopment possibilities with a MatCon™ cover.
Community acceptance	9. Community acceptance of the technology is likely because of the redevelopment possibilities with a MatCon™ cover.

construction industry, which should result in permanence of the MatCon™ cover.

2.2.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

The MatCon™ technology does not involve treatment of waste or contaminated material; therefore, it cannot reduce toxicity or volume through treatment. However, the MatCon™ cover reduces the mobility of contaminants in the landfill by minimizing entry of water into the waste; as a result, leachate production and migration is minimized.

2.2.5 Short-Term Effectiveness

Depending on the size of the cover required, the MatCon™ technology can be installed in as little as one day, to within a few weeks and immediately prevents entry of water into the waste. Therefore, the MatCon™ technology provides short-term effectiveness by minimizing formation of leachate.

2.2.6 Implementability

The ease of implementation is an attractive feature of the MatCon™ technology. The proprietary binder is shipped to the hot mix plant nearest to the site, and the mix is prepared under WCC supervision. Paving equipment available from local paving contractors can be used to install the MatCon™ cover in a few weeks.

2.2.7 Cost

The installation cost varies from $124,000 to $140,000 per acre and is less than that for RCRA Subtitle C clay and geosynthetic covers. In addition, the time required to install the MatCon™ cover is significantly less than that for clay and geosynthetic covers. Mobilization and demobilization costs are also less than for clay and geosynthetic covers.

2.2.8 State Acceptance

MatCon™ has been included in state-approved design specifications of landfill covers installed at sites in the states of California, Colorado, Delaware, Florida, Illinois, Kentucky, New Mexico, Texas, and Washington. Approval is based on the low permeability of the cover and the redevelopment or reuse possibilities for the MatCon™ cover surface.

2.2.9 Community Acceptance

The states mentioned in Section 2.2.8 approved the MatCon™ cover because of community acceptance for site redevelopment at closed landfills. The ease of maintenance for the MatCon™ cover is also attractive to communities.

2.3 Technology Applicability

The MatCon™ technology can be used as a final cover at many hazardous waste sites where a firm foundation is available or can be constructed. The MatCon™ cover offers a major advantage over RCRA Subtitle C or D covers when site reuse is planned. The following are a few of the site reuse possibilities:

- Parking or staging area for equipment and vehicles
- Material processing and treatment pads
- Petroleum hydrocarbon-resistant surface for fueling operations
- Light industrial manufacturing and warehousing
- Sports facilities, such as tennis courts and running tracks

The MatCon™ cover at the TCL site has been used as a staging area for garbage trucks and recycling vehicles since the day it was installed. In addition, a large fuel oil tank placed on the cover is used for fueling the vehicles.

The demonstrations at the DAFB and TCL sites have proven the applicability of the technology in wet and cold climates. An additional demonstration is planned in 2003 at Kirtland Air Force Base in Albuquerque, New Mexico.

2.4 Limitations of theTechnology

The limitations of the technology can be grouped under three categories: site characteristics, quality control, and extent of site reuse. These limitations are discussed in the following subsections.

2.4.1 Site Characteristics

MatCon™ cover applications require the following site conditions:

- The subgrade to receive the MatCon™ cover must be firm and unyielding to support compaction of the MatCon™ asphalt during construction.

- The subgrade to receive the MatCon™ cover must have slopes of less than 3:1 (height:volume) for the safe use of compacting and paving equipment during installation.

- The subgrade to receive MatCon™ must have a slope of greater than 1.5 percent to facilitate drainage and minimize surface water ponding.

- The subgrade must be constructed to a grading tolerance of plus or minus 0.5 inch (1.3 cm).

2.4.2 Quality Control

The MatCon™ cover has to be prepared and installed under strict quality assurance (QA) procedures in accordance with WCC's specifications and construction QA program. The MatCon™ mix must be produced in a local hot mix plant under the WCC QA program.

2.4.3 Site Reuse

Though heavy surface use on a MatCon™ cover is possible, heavy container stacking, extraordinarily heavy or repeated loads, sharp point source loading, misuse, or use of heavy tracked equipment might compromise its integrity. Such heavy surface uses can be accommodated through customized designs, formulations, and construction methods. WCC prepares site specific Operations and Maintenance Plans for each installation and the potential future surface uses.

Section 3
Economic Analysis

The primary purpose of this economic analysis is to estimate costs of utilizing the MatCon™ cover to provide source control at hazardous waste sites. Site-specific factors affecting cost, the basis of the economic analysis, cost categories, and cost per acre of MatCon™ installation are described below.

Costs have been divided into four categories that are applicable to this technology. The four categories are:

- Site preparation
- Permitting and regulatory
- Labor
- Supplies and consumables

Table 3-1 shows the estimated costs for preparing the MatCon™ mix and installing the cover on one acre.

The following eight categories typically associated with cleanup activities at Superfund and RCRA-corrective action sites are not applicable to the MatCon™ technology.

- Capital equipment
- Startup costs
- Demobilization
- Utility costs
- Effluent treatment and disposal
- Residuals and waste shipping and handling
- Equipment maintenance and modifications
- Analytical and monitoring costs

MatCon™ is a containment system technology, not a treatment technology that reduces waste toxicity. The equipment used to install the MatCon™ cover is conventional paving equipment, and this task is subcontracted by the project owner, engineer, or WCC to a qualified local paving contractor. Therefore, no startup, demobilization, or capital equipment costs are involved. The cost of equipment (capital and operating) for a MatCon™ installation cannot be separated out from the total equipment costs of the paving contractor and is included in the labor overhead under labor costs.

MatCon™ cover installation does not require separate utility costs, and the fuel required to run the paving equipment is included in the labor costs charged by the paving contractor. The technology does not treat waste; therefore, no cost is associated with effluent treatment and disposal, residual and waste shipping and handling, or analytical and monitoring. The vendor-specified construction quality control (CQC) testing is included in the labor costs.

3.1 Site-Specific Factors Affecting Costs

Two site-specific factors impact the cost of MatCon™ cover installation. These are (1) physical site conditions related to the subgrade and (2) geographical location, which affects transportation costs for the hot mix and paving contractor costs. The size of the paved area did not have much impact on the cost per acre for MatCon™ installation.

The variation in costs due to physical conditions at the site is demonstrated in costs incurred at the DAFB and TCL sites. The subgrade at the TCL site was constructed over municipal waste and required 8 inches (20 cm) of crushed rock, compared to 6 inches (15 cm) at the DAFB site (a difference of $3,000 per acre). Labor costs and cost of supplies were also less at DAFB compared to the

Table 3-1. Estimated Costs Associated With MatCon™ Installation

Cost Category	Estimated Cost Per Acre (Dollars)
Site preparation	7,000 to 10,000
Permitting and regulatory	2,000
Startup	0
Labor	35,000 to 45,000
Supply and consumables	80,000 to 83,000
Utilities	0
Effluent treatment and disposal	0
Residual and waste shipping and handling	0
Analytical and monitoring	0
Maintenance and modifications	0
Demobilization	0
Total cost per acre	124,000 to 140,000

TCL site because of site proximity to the local asphalt plant (a difference of $12,000 per acre).

The costs presented in this analysis are based on conditions at the DAFB and TCL sites. Because these costs were not independently verified at the sites, all costs presented in this section were provided by WCC.

3.2 Basis of Economic Analysis

The following assumptions were made for this economic analysis.

- The site is located within 20 miles (32 kilometers [km]) of the asphalt plant.
- Suitable access roads are available.
- The site has relatively firm soils with a bearing capacity of about 1 ton per square foot.
- The site is relatively flat and dry.
- A qualified paving contractor is available in the project area.

3.3 Cost Categories

A discussion of the four cost categories applicable to the MatCon™ cover installation and the elements associated with each category is provided below. These costs are based on the costs per acre experienced by WCC at the DAFB and TCL sites.

3.3.1 Site Preparation

The costs associated with site preparation include grading the surface to remove soft spots, creation of the required slope, and placing crushed rock subgrade to support the MatCon™ cover installation.

Sites that require a substantial amount of fill or reinforcing to repair soft spots and form a firm base will have significantly higher site preparation costs. At the TCL site, soils overlying municipal waste could be prepared by placing about 8 inches of crushed rock to form a suitable subgrade. Costs at the DAFB site for site preparation were somewhat lower because of a firmer base. The site preparation costs ranged from $7,000 to $10,000 per acre. Site preparation is typically performed by a local civil grading contractor.

3.3.2 Permitting and Regulatory Costs

These costs are dependent on the type of waste and the environmental laws, regulations, and ordinances of federal, state, and local jurisdictions. Because installation of the MatCon™ cover provides source control and facilitates site reuse, it is not expected to require much effort to obtain the required permits. Permitting and regulatory costs are estimated at $2,000 per acre.

3.3.3 Labor Costs

These costs include the cost of personnel at the asphalt plant, for the truck drivers to transport the mix to the site, for the crew required to lay and compact the mix at the site, and supervisory personnel. The cost of equipment at the asphalt plant and for the paving contractor are included in the labor cost charged by the contractor. The 3.6-acre (1.5-hectare) site at TCL required about two 10-hour days to complete installation of the 4-inch-thick (10.2-cm) MatCon™ cover. The DAFB costs were somewhat lower because the asphalt plant was close to the site.

According to WCC, the labor costs for MatCon™ installation ranged from $35,000 to $45,000 per acre. Of this amount, the cost of supervising personnel from WCC and the site owners was 15 percent, cost of the field crew was 50 percent, cost of the plant personnel was 20 percent, and the cost of truck drivers was 10 percent.

3.3.4 Supplies and Consumables Costs

Supplies and consumables costs include the cost of the proprietary binder, bitumen and the aggregates required to prepare the hot mix. The proprietary binder is expensive since it has not been widely used for hazardous waste covers. According to WCC, the cost of the binder per acre of cover is $77,400 (current published catalog pricing), and the cost of aggregate and bitumen per acre ranges from $3,000 to $10,000, depending on the local cost of aggregate.

3.4 Cost Per Acre of Matcon™ Cover

Based on the cost breakdown discussed in Section 3.3, the total cost per acre of MatCon™ cover ranges from $124,000 to $140,000. At the time of this report, WCC's published catalog price for the MatCon™ binder and technical support (including mix design, technical support, onsite MatCon™ Guide Specification CQC, and related testing) is $77,400 per acre for a nominal 4-inch thick lift. The difference between this and the $124,000 to $140,000 per acre estimate range is directly related to the cost of the hot-mix aggregates, hot-mix blending, hot-mix haul from the facility to the job site, lay-down and compaction. This latter component ($39,600 to $54,600 per acre) is a function of the local asphalt paving market forces and proximity of the hot-mix plant to the job site.

This cost compares favorably with the cost per acre of RCRA Subtitle C covers, which ranges from $250,000 to $350,000, depending on the local availability of appropriate soil and drainage materials (Dwyer 1998).

Section 4
Technology Effectiveness

This section discusses the two SITE demonstrations that were conducted to evaluate the effectiveness of the MatCon™ technology. This discussion addresses the construction of the MatCon™ covers, the measurements that were completed to determine conventional asphalt and MatCon,™ performance and the demonstration results and conclusions.

4.1 Description of the Installed Covers

The installation of the MatCon™ cover and the field tests at the DAFB and TCL sites are discussed below. The locations of these two sites are shown in Figure 2-1 (DAFB site) and in Figures 2-2 and 2-3 (TCL site).

4.1.1 DAFB Site

This section describes the cover at the DAFB site.

4.1.1.1 Cover Installation

WCC installed the MatCon™ cover system at DAFB in April 1999. The cap covers 124 by 220 feet (38.4 by 67.1 meters) (see Figure 4-1). The cover consists of three, hydraulically independent sections, as follows:

- Section I: 12-inch-thick (30.5-cm) MatCon™
- Section II: 4-inch-thick (10-cm) MatCon™
- Section III: 4-inch-thick (10-cm) conventional asphalt

A subsurface drainage collection (leak detection) system was constructed in Section I (Figure 4-2). The system consists of a 4-inch-thick channel of open-graded asphalt between two 4-inch-thick MatCon™ layers. The subsurface drainage system divides Section I into quadrants; the drainage layer beneath each quadrant flows into a separate 3-inch-diameter (7.6-cm) high density polyethylene (HDPE) pipe (Figure 4-3).

The area covered by the MatCon™ and conventional asphalt is small, so no cold joints were required. An elaborate design specification was not prepared for this site.

WCC contracted with a local asphalt contractor to construct the conventional asphalt and MatCon™ covers. The 6-inch-thick (15-cm) subgrade was prepared with crushed rock by DAFB personnel according to the requirements of WCC. However, for the 12-inch-thick (30-cm) MatCon™ section, no crushed rock was used in the subgrade. The soil was compacted to the grade specified by WCC, and the asphalt contractor placed the 12-inch-thick (30-cm) MatCon™ section using the material specified by WCC.

The installation was completed in about two days. WCC provided the special binder to the local hot mix plant, and the plant prepared the MatCon™ material according to the specifications provided by WCC. WCC prepared a video of the complete MatCon™ installation and submitted it to EPA.

4.1.1.2 Drainage System

A drainage ditch, a metering pit, and a lysimeter sump were installed during March 2000 to monitor runoff from the cover and infiltration into the lysimeter section of the cover. All hydrologic monitoring points were located on the down gradient side of Section I of the cover.

To monitor surface runoff, a lined ditch was constructed along the down gradient side of the cap, and berms were constructed on three sides to direct the runoff into the drainage ditch (Figure 4-4).

The ditch flows into a 4-ft by 4-ft by 4-ft deep (1.2- by 1.2- by 1.2-meter) metering pit (Figure 4-5). Flow into the metering pit was measured with a flow meter prior to surface discharge.

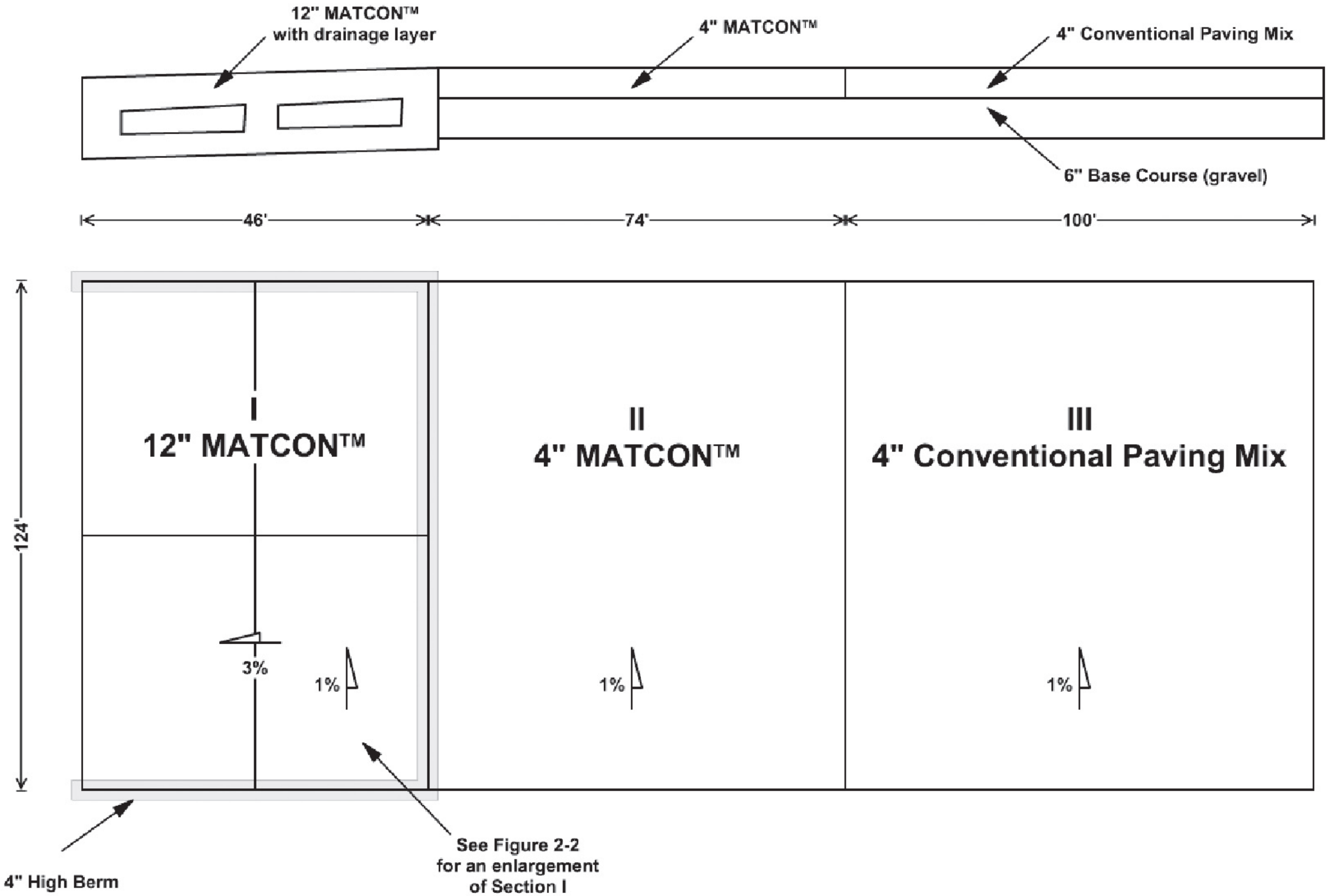

Figure 4-1. MatCon™ liner and cover system.

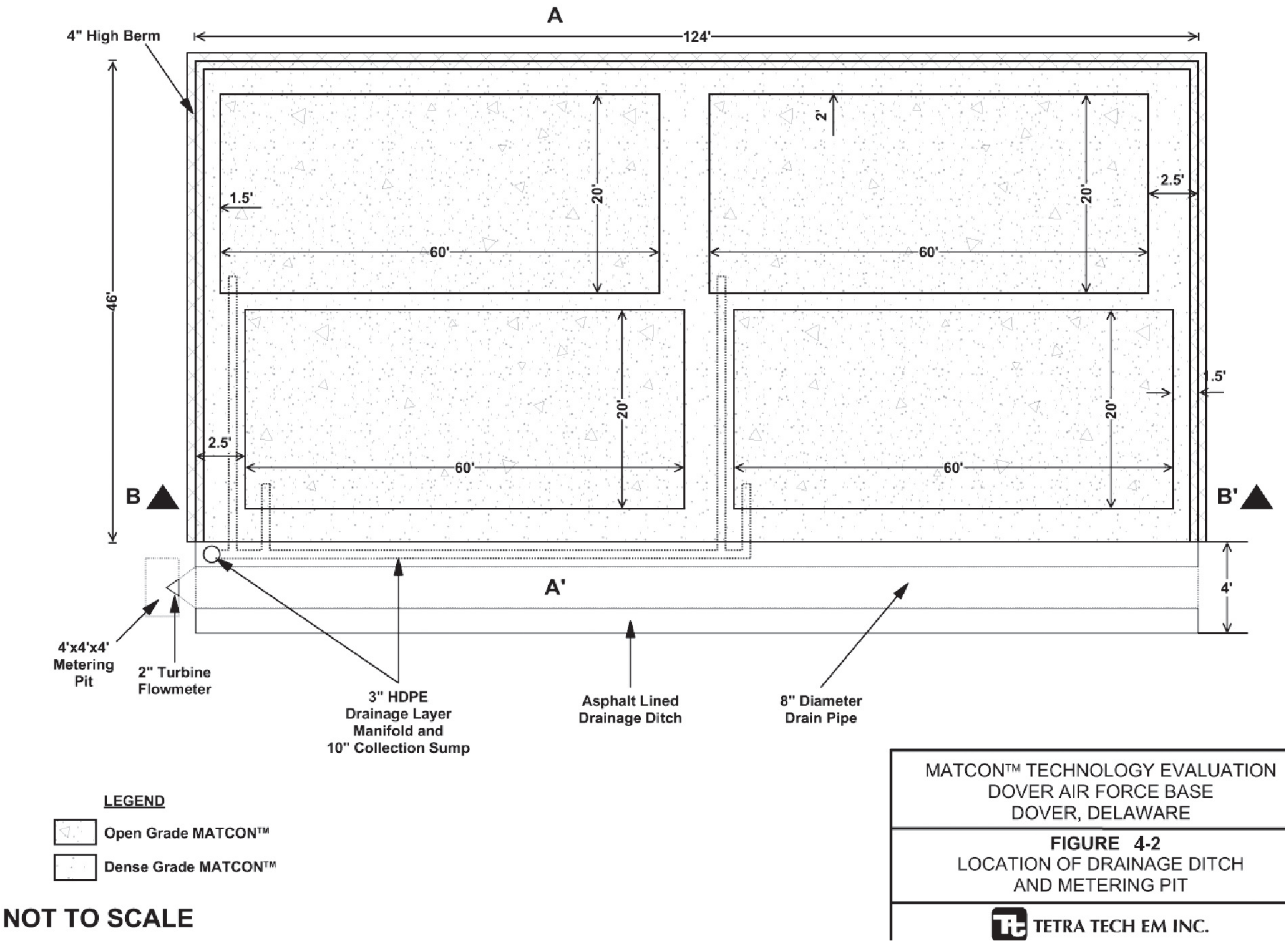

Figure 4-2. Location of drainage and metering pit.

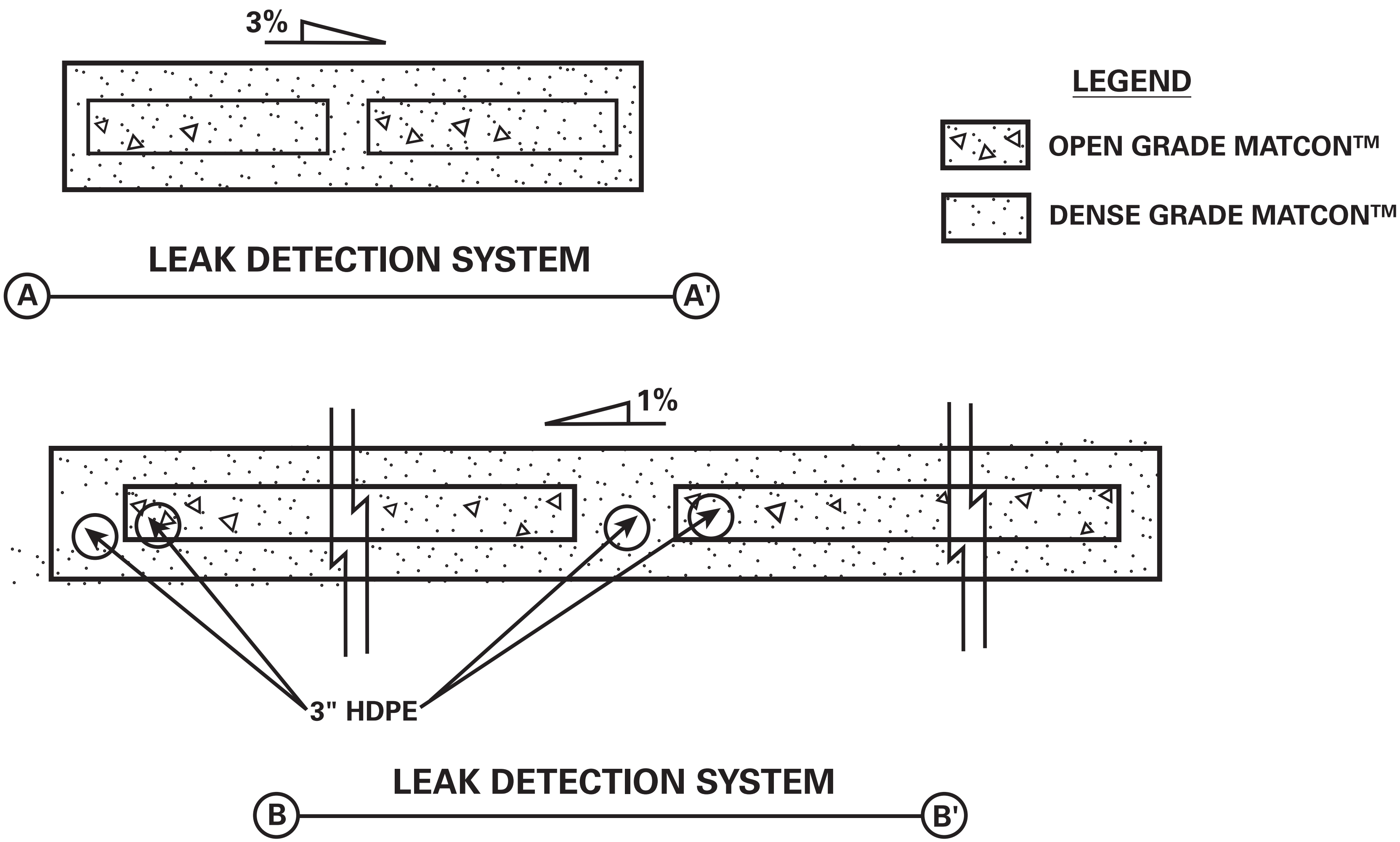

Figure 4-3. MatCon™ liner and cover cross-sections A-A' and B-B'.

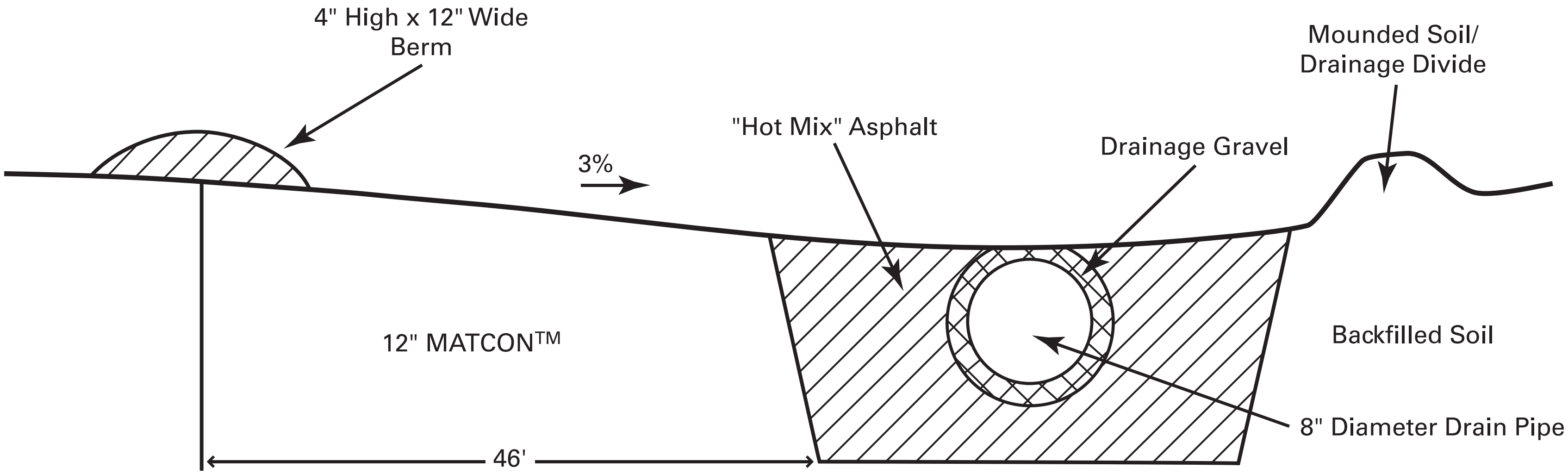

Figure 4-4. Ditch cross-section.

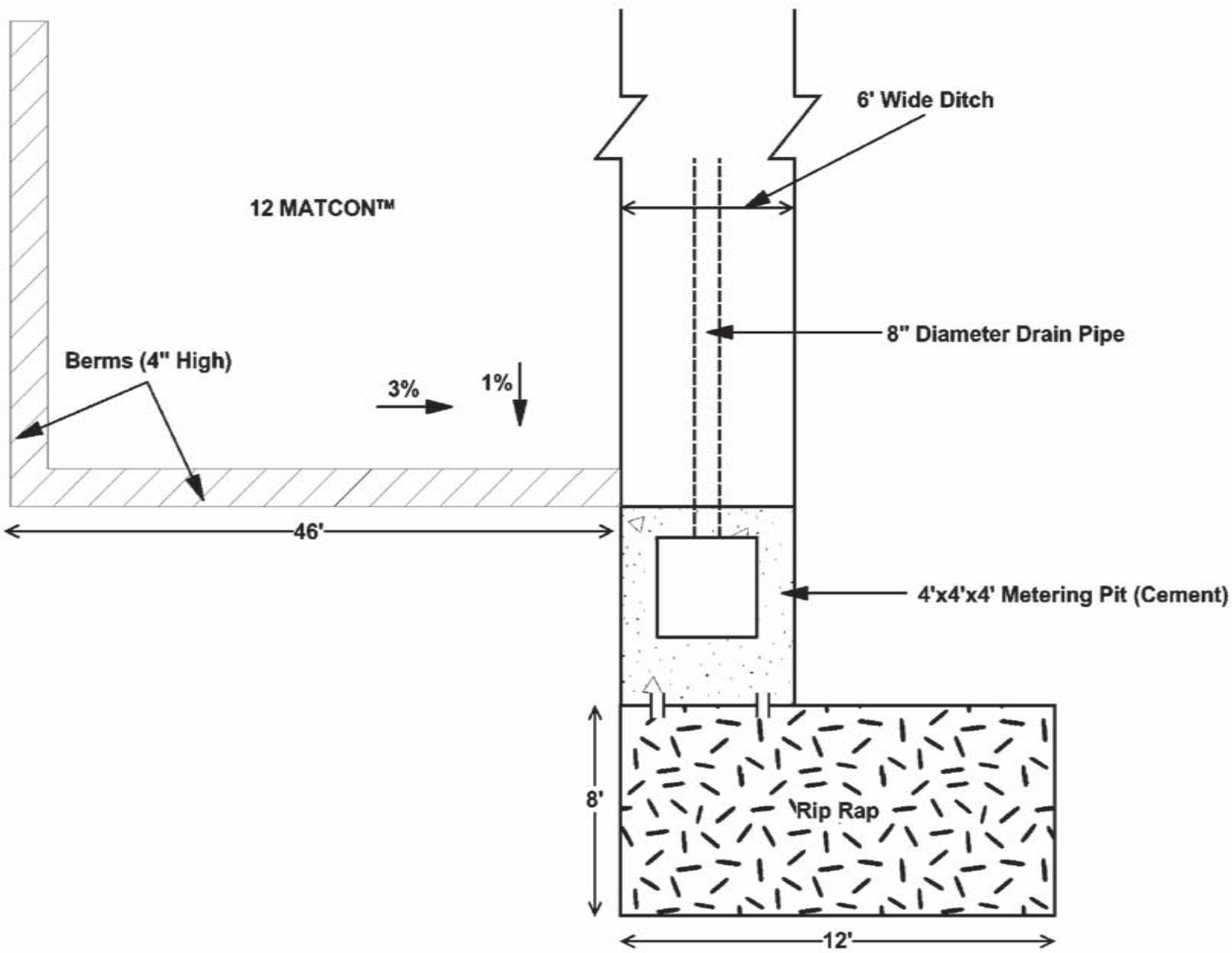

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Figure 4-5. Monitoring pit/french drain.

To monitor infiltration, the four 3-inch-diameter (7.5-cm) HDPE pipes leading from the drainage layer were connected to a 10-inch-diameter (25.4-cm) sump, as shown in Figure 4-6. Field installation of this sump utilized a single piece of HDPE pipe.

4.1.2 Tri-County Landfill

MatCon™ was installed at the TCL site in Elgin, Illinois, by WCC as a final cover system in November 1999. The project consisted of a 3.6-acre (16,092 m^2) site that had a subgrade previously prepared for WCC's final grading and subsequent MatCon™ installation. WCC prepared the final grade for paving, constructed the test section, and installed the MatCon™ cover over a 2-week period (Figure 4-7).

As part of the MatCon™ cap installation by WCC for the TCL site, the patented three-layer leak detection system was proposed. Review of the system design by the U.S. Army Corps of Engineers (COE) and their subsequent comments required the incorporation of several modifications for the lysimeter that was installed. Specific changes in the design included the use of a HDPE membrane liner as the underlying impermeable barrier. This was placed on top of a panel of conventional asphalt, over which a geotextile fabric was placed for protection and cushion purposes. The rounded drainage rock material was placed over the geotextile fabric as a replacement for the open-graded MatCon.™ The entire installation was then covered with the final MatCon™ panel (Figures 4-8 and 4-9). The lysimeter pipe and sump were installed by Waste Management, Inc. (WMI).

4.1.3 Installation Details

Installation of the MatCon™ covers at both the DAFB and the TCL sites was observed to document the construction details and construction quality.

4.1.3.1 Subgrade and Drainage Systems

At the TCL site, the underlying subgrade was firm and unyielding, and was compacted using conventional heavy load proof-rolling procedures. Surface grades of 1 to 3 percent were used to facilitate drainage of the final surface. The subgrade was inspected and accepted by WCC personnel. The surface was finish graded to within the tolerance of ± 0.5-inch (1.2-cm) measured using a 10-foot (3-meter) straight-edge level prior to paving.

At the TCL site, coarse aggregate placed as the drainage layer of the lysimeter facilitated the conveyance of water horizontally but could not be compacted to a firm and unyielding condition. This resulted in difficulties during the paving operation.

All retaining sidewalls, piping, and sump appurtenances were designed to be water tight. Sump design prevented intrusion from rain and snow (gasketed lid) and included protection from freezing temperatures, methods to adjust to barometric pressure changes and minimize condensation (adequate weatherproof venting), and measures for secure access (locking lid).

4.1.3.2 Cover Construction Quality

At the TCL site, a crack at a cold joint appeared after a prolonged period of cold weather in January 2000. The edge of the asphalt application is typically more difficult to compact because there is no lateral support for the roller. When the asphalt is hot, the edges weld together properly. However, an edge that is allowed to cool overnight is then very difficult to bond to the next day's first application of asphalt. In addition, it is especially difficult to increase density in the cold joint area. The result is a zone along the cold joint that may be poorly compacted. Raveling, or separation of aggregate particle fines from the surface or edges of the compacted asphalt, can occur in these zones. Although WCC has determined that poor quality workmanship was the cause, a better design has since been developed to overcome the raveling and reduce dependency on workmanship. A wedge-shaped cold joint panel (3-meters wide) proved to be a good design in terms of bonding and providing a good impermeable mat. The new design includes removal of some material and a heavy tack coating.

The crack that appeared at the cold joint at the TCL site was routed and sealed. The zone along the cold joint, about 3 feet wide (0.91 meter), was sealed with mastic to decrease the permeability by filling the surface voids.

4.2 Evaluation Procedures

Procedures used to evaluate the MatCon™ cover and compare it with conventional asphalt were described in the Technology Evaluation Plan/Quality Assurance Project Plan (TEP/QAPP) (Tetra Tech 2000). Field sampling of the slabs and cores at the DAFB site was completed in August 1999. Samples were obtained at the TCL site immediately after cover installation in November 1999, and then again in April 2000 to obtain samples in a portion of the

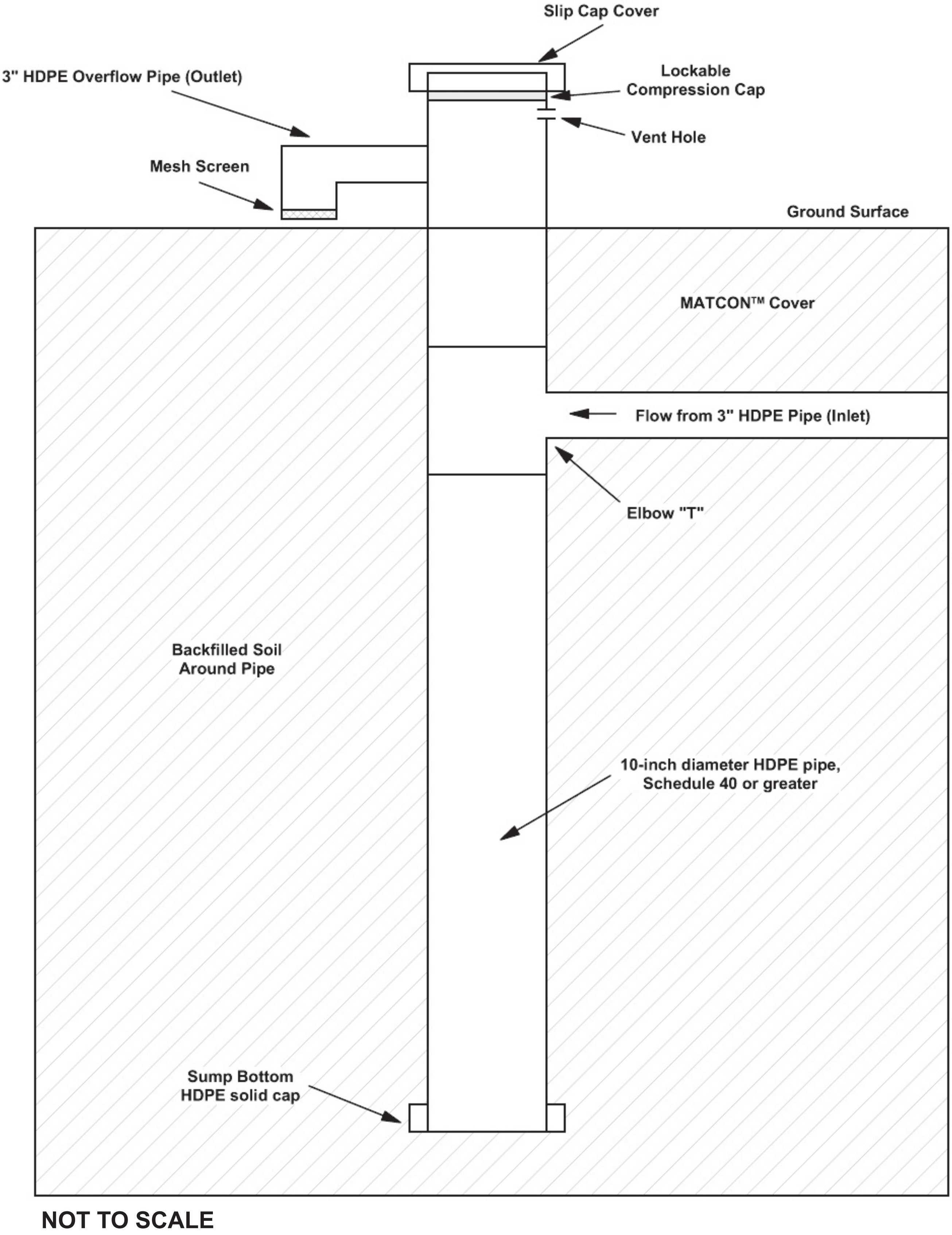

Figure 4-6. MatCon™ liner and cover system leak detection sump.

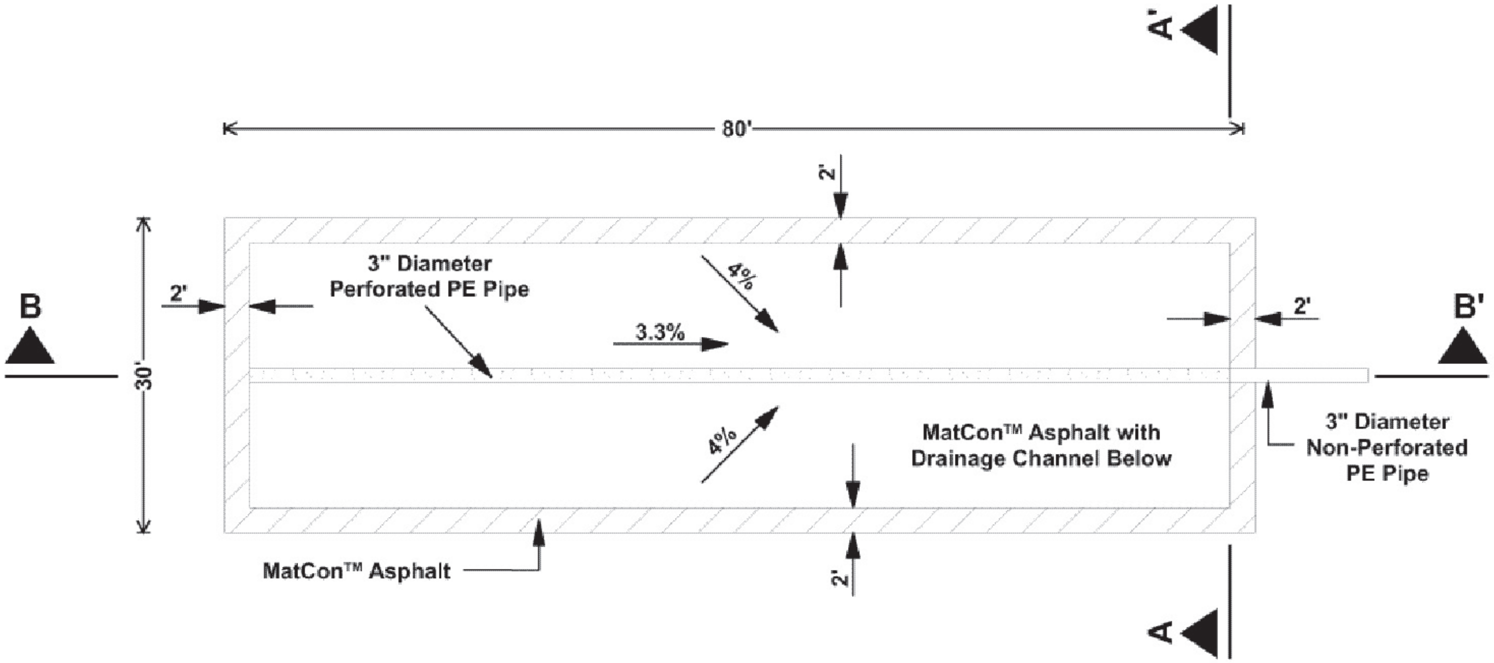

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Figure 4-7. Plan view of the MatCon™ cover.

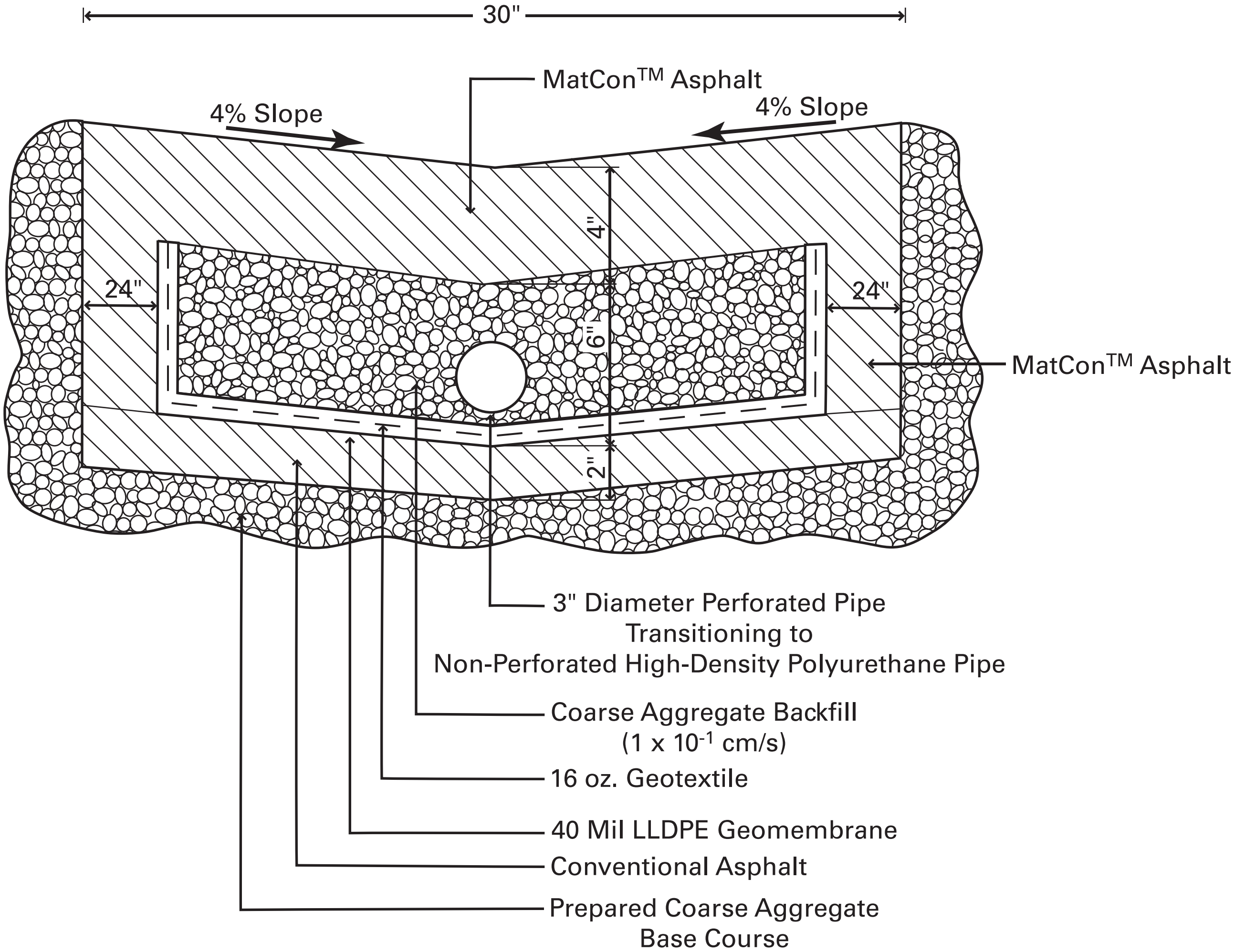

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Figure 4-8. Section A-A'

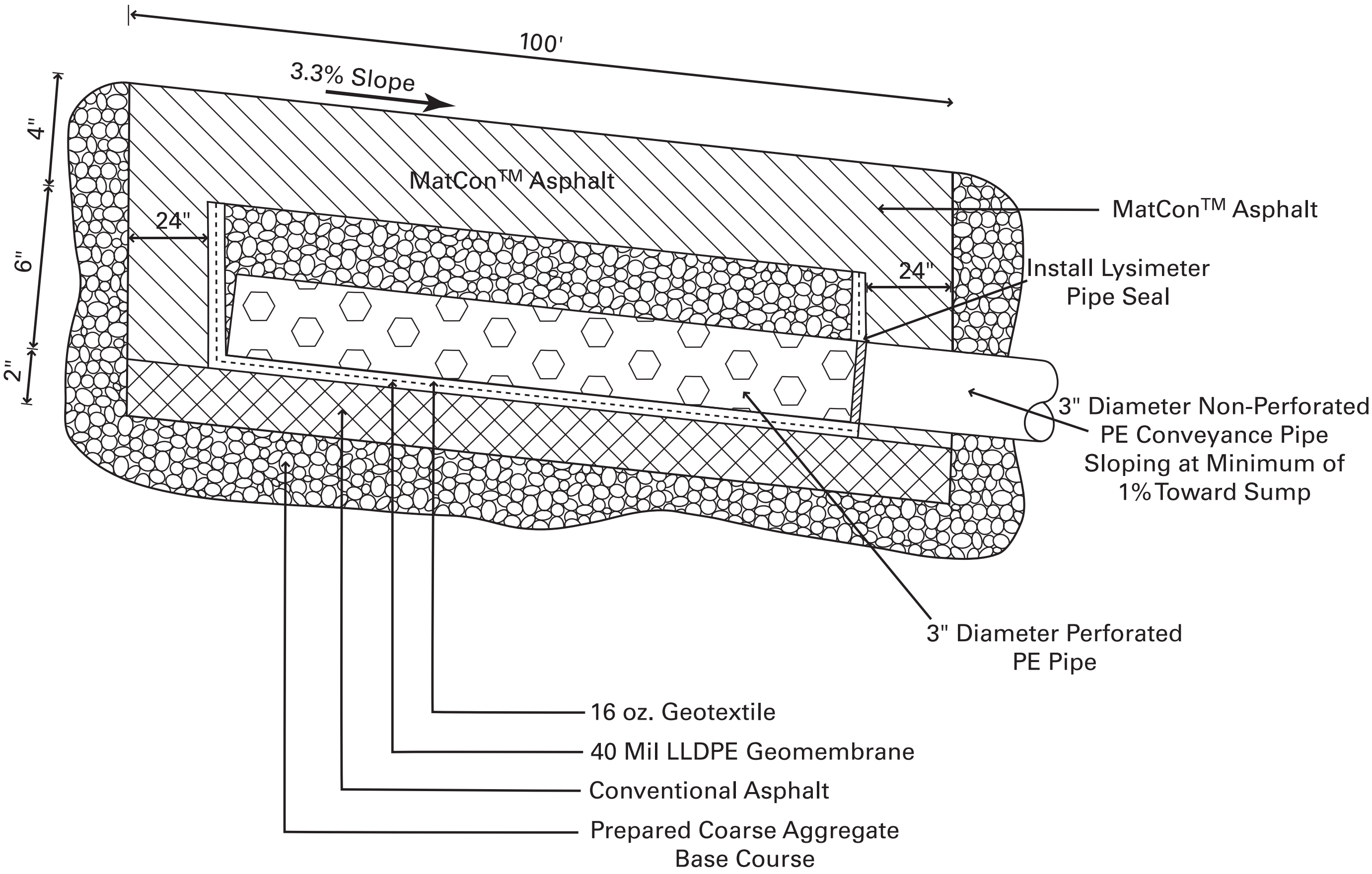

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Figure 4-9. Section B-B'.

MatCon™ cover where a crack was observed. Extensive testing of slab and core samples from the MatCon™ and conventional asphalt sections was performed for the DAFB site. However, only limited laboratory testing was performed on the TCL cores.

The sampling methods, field and laboratory tests, and the quality assurance procedures used for the field and laboratory testing are detailed in this section.

4.2.1 Field Testing

This section discusses field testing at DAFB and TCL.

4.2.1.1 Basis of Measurement of Field Permeability

Field permeability of the MatCon™ was calculated during periods of rainfall by measuring the drainage volume into the sump and using Darcy's Law. The permeability (k) was calculated using the following equation.

$$k = QL / A\,t\,h$$

where Q = flow into the sump
L = nominal thickness of the MatCon™ cover
A = area of the cover
t = duration of the test
h = hydraulic head (as described below)

The variable of hydraulic head (h) in the above equation was based on the reported USGS rainfall amount during each monitoring period. However, several assumptions were required, which caused uncertainties in the calculation (see Section 4.4.1). Therefore, constant-exposure ponding tests were established to better estimate the field permeability. For ponding test permeability calculations, hydraulic head (h) was equal to the thickness of the MatCon™ layer plus the height of the water ponded on the surface of the cover. Field measurements of water infiltration into the MatCon™ cover were completed at the DAFB site from April through July 2000. In addition, attempts were made to obtain a hydrologic balance for the DAFB site during April through June 2000 using a flow meter to measure runoff from the MatCon™ cover.

4.2.1.2 DAFB Site

Data for the volume of drainage layer infiltration and surface runoff were collected on a regular basis. These data were recorded in a field book, and Tetra Tech personnel performed hydrologic calculations. During each trip, the drainage layer sump (DLS) was inspected for integrity, and a water level measurement was taken. The sump was evacuated for the next measurement. A flow meter reading was obtained, and the monitoring pit was pumped out.

Data for the DLS were collected using a measuring tape. The depth of the water column accumulated in the sump was recorded in triplicate. The average depth measurement was then converted to a volume in gallons. This volume was then used to calculate a permeability value using Darcy's law, as described above.

Data from the surface drainage flow meter were more problematic. Consistent cumulative measurements were difficult to record due to the recurring heavy rainfall and subsequent flooding of the site. Therefore, reliable flow data could not be obtained.

A 6-hour ponding test was conducted that consisted of applying a head of approximately 2.5 inches (6.2 cm) of water over the MatCon™ Section I area while monitoring the flow in the DLS.

4.2.1.3 TCL Site

Monitoring trips were conducted to collect data for the volume drainage layer infiltration and surface runoff. Bi-weekly trips were made to the TCL site to measure the water level in the sump. The trip was planned after a rainfall event of 1 inch (2.5 cm) or more during the past 24 hours. After the measurement, the sump was bailed out for the next measurement. Using the sump water levels, , the drainage volume was determined, and the permeability of the MatCon™ cover was calculated using Darcy's law.

A 4-inch-high (10-cm) asphalt berm was constructed around the perimeter of the test section on top of the MatCon™ cover. In addition, berms were added between the edge berms, forming a series of terraces where water could be impounded. Water from both a tank truck and heavy rainfall filled the terraces to an average depth of about 2 to 2.5 inches (5.1 to 6.2 cm) and was maintained for almost 48 hours. During this period, the water inflow to the sump was monitored and used to calculate the permeability of the MatCon™ cover. A steady-state condition was reached in about 6 hours.

4.2.2 Sampling Methods

The objectives of the field sampling program were to obtain representative samples of the MatCon™ and conventional asphalt covers for subsequent laboratory testing. This section describes the sampling objectives, the sampling locations, and sampling procedures for the MatCon™ and conventional asphalt covers.

4.2.2.1 Sampling Objectives

The following general objectives were used for all sampling activities:

- Collect samples in a manner that ensures they will represent the medium being sampled
- Maintain proper chain-of-custody control of all samples, from collection to testing
- Follow QA/QC procedures appropriate for EPA National Risk Management Research Laboratory (NRMRL) Applied Research Projects

4.2.2.2 Sampling Locations and Procedures

The cover at the DAFB site was planned to be a long-term functioning cover, and was not constructed solely for demonstrations purposes. Therefore, the sampling strategy sought to minimize the amount of area impacted by sample coring, so that repairs to the cover could be implemented more effectively. It was decided that confining the sample cores to one subarea of the cover would still provide representative samples because the entire cover was installed in two days using the same work crew, materials, and procedures for all areas of the cover. Asphalt core and slab samples were collected from a 3-ft by 3-ft (0.91-by 0.91-meter) sampling area in Section I and from 6-ft by 8-ft (1.8- by 2.4-meter) sampling areas in Sections II and III, as shown in Figure 4-10. The number of samples taken in each of the three sections of the demonstration cover is listed in Table 4-1.

PRI collected samples from the locations shown on Figure 4-10 on August 26 and 27, 1999. A coring machine was used to obtain the 4-inch-diameter (10-cm) and 6-inch-diameter (15-cm) cores, and a diamond-toothed saw was used to obtain the slab samples. Areas where samples were collected were then patched with hot mix asphalt by WCC.

Samples at the TCL site were not obtained from the 30-ft by 80-ft (9.1-by 24.4-m) test section. They were obtained instead from an adjacent location where light poles were to be installed on the cover. Six cores were obtained initially, and five more cores were obtained in April 2000 at the location of a crack. The only testing that was done with these cores was aggregate properties, void space, and hydraulic permeability.

4.2.2.3 Sample Identification and Handling

Samples obtained by PRI Asphalt Technologies, Inc. (PRI) were identified by location and sample number, and were packed carefully in padded containers. Chain-of-custody forms were filled out by PRI to document the acquisition of the field samples. The containers were transported by PRI personnel in a van to PRI's laboratories in Tampa, Florida. The PRI personnel in the laboratory signed the chain-of-custody forms to document receipt of the samples. PRI had custody of the samples from field acquisition to receipt in the laboratory.

Laboratory tests run on the samples are listed in Table 4-2; a description of each of these tests is provided in the TER.

4.2.3 Laboratory Testing

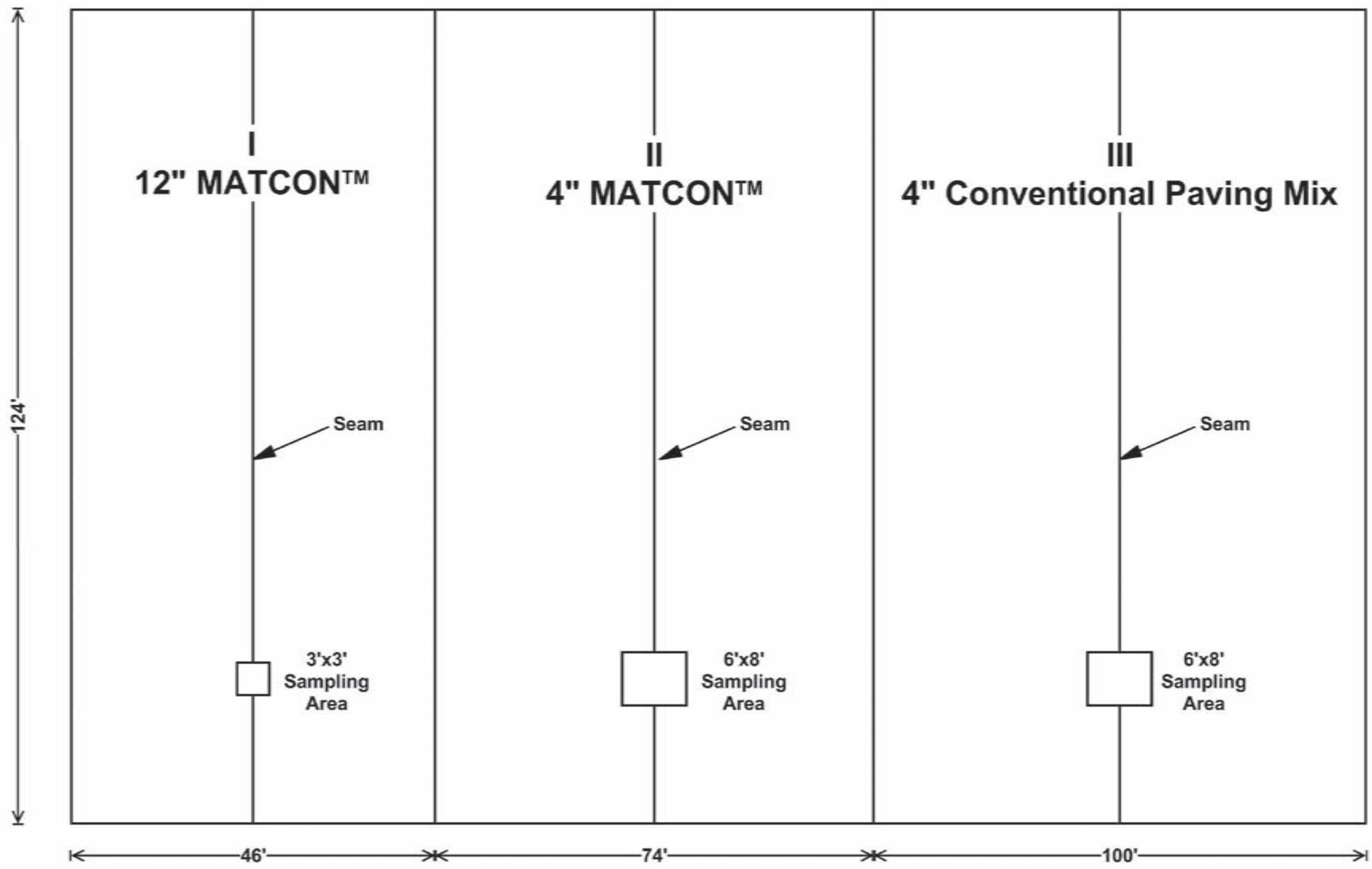
The testing methods selected for the project are those standardized by the American Society of Testing and Materials (AS™) and the American Association of State Highway and Transportation Officials (AASHTO). Calibration of equipment used to perform the standardized tests (AS™ and AASHTO) was performed, when required, as recommended in the procedure (AS™ 1997).

For the flexural test that simulates the effect of differential settlement on the MatCon™ cover, no standardized test is available; however, Dr. Ronald Terrel of Terrel Research devised a test that was used for this demonstration. These laboratory testing methods are described in further detail in the Quality Assurance Project Plan (QAPP).

4.2.4 Quality Assurance and Quality Control Program

The overall objective for this evaluation was to produce well-documented data of known quality. Quality is measured by monitoring data precision and accuracy, completeness, representativeness, and comparability.

The evaluation was designed to ensure that a sufficient number of samples were collected to represent the cover material at each given site and that each sample was taken in a manner that ensures representativeness to the extent practical.



NOT TO SCALE

Figure 4-10. Sampling area locations.

Table 4-1. Cover Sample Type, Numbers, and Labeling-DAFB Site

Sample Type	Approximate Size	Quantity	Location	Label
		5		4-1 through 4-5
		5		5d-1 through 5d-5
	4” (10 cm) diameter	5		2a-1 through 2a-5
Core		12	Section III 4” (10 cm) Conventional Paving Mix	7-1 through 7-12
	6” (15 cm) diameter	8		2b-1 through 2b-8
Slabs	14” x 40” (35 x 100 cm)	4		A, B, C, D
		5		4-1 through 4-5
	4” (10 cm) diameter	5		5d-1 through 5d-5
		5		2a-1 through 2a-5
Core		12	Section II 4” (10 cm) MatCon™	7-1 through 7-12
	6” (15 cm) diameter	8		2b-1 through 2b-8
Slabs	14” x 40” (35 x 100 cm)	4		A, B, C, D
Slabs	14” x 14” (35 x 35 cm)	4	Section I 12” (30 cm) MatCon™	A, B, C, D

Table 4-2. Characterization Testing on Asphalt Samples-DAFB Site

Parameter	Sampling Location Section I	II	III	Proposed Test	Samples Used
Hydraulic Conductivity		X	X	ASTM D-5084 and AASHTO T-283	4" diameter cores, 3 replicates
Flexural Properties		X	X	Differential Settling Test at 25 ºC (one month duration)	4" x 4" x 36" slab[2] 2 replicates
Load Capacity/ Deformation		X	X	Resilient Modulus at 25 ºC ASTM D-4123	4" diameter cores, 3 replicates
Shear		X	X	Shear Test at 4, 20, and 40 and 60 ºC AASHTO TP 7	6" diameter cores, 2 replicates per temperature per section
Joint Integrity (permeability)[3]		X	X	ASTM 5084	4" diameter cores, 3 replicates
Tensile Strength		X	X	AASHTO TP 9	4" x 4" x 10" slab[2], 3 replicates
Thermal Crack Resistance		X	X	AASHTO TP 10	4" x 4" x 10" slab[2], 3 replicates
Degradation and Accelerated Weathering Properties		X	X	ASTM D-5084 AASHTO TP 31	4" diameter cores Aged using water, ultra-violet light, and kerosene. Tested at initial, 1 week, 1 month, and 2 months, 2 replicates
Voids and Asphalt Binder Content		X	X	ASTM D-3203 and AASHTO TP 53	4" diameter cores, 3 replicates
Layer Thickness	X	X	X	Direct measurement with ruler	cores and slabs, 3 replicates
Aggregate Properties		X	X	ASTM C-136, C-131, C-127, D-2172	4" diameter cores, 3 replicates
Hydraulic Transmissivity (Drainage layer only)	X			Modified ASTM D-5084	12" x 12" x 12" slabs[2], 2 replicates

Notes:
1 Cores from the TCL site were analyzed for hydraulic conductivity only
2 Slabs were cut to size using a diamond-toothed saw
3 After cracking and prior to joint repair

The comparability of the data was maximized by using standard AS™ and AASHTO methods. Comparability was also maximized through the use of consistent sample collection techniques and field measurement methods throughout the evaluation.

4.2.4.1 Field Quality Control Program

Field quality control procedures consisted of a water-level meter precision check at the TLC site. This quality control check was not implemented at the DAFB site because a measuring tape was used to obtain the depth to water. After each field measurement event, the following precision-check procedure was executed. First, a graduated cylinder was fitted with a measuring scale divided into 0.10-inch (0.25-cm) increments. The vessel was then filled with water and the field water-level meter was used to obtain a measurement in the vessel. This measurement was taken three times. If the three measurements agreed within 0.1-inch (0.25-cm) of each other, the water-level meter was considered acceptable.

Each water-level measurement taken in the sump was taken three times to ensure precision. These three measurements were then used to calculate the relative percent difference (RPD). The measurements were accepted if they met the criteria of being less than a RPD of 2. If accepted, the three values were averaged and used to calculate the MatCon™ permeability.

The accuracy of the in-line volumetric flow meter was determined by field checking using a bucket and stopwatch method. The procedure required that flow occurred at the time of the field check, thus these checks had to be executed during rain events. The beginning flow rate registering on the flow meter was recorded to start. Then a 3-gallon (11.4-liter) bucket was filled at the outflow of the runoff discharge pipe while elapsed time was measured. The volume was then divided by the elapsed time to give a rate, which was compared to the rate read from the flow meter. Lastly, the rate was again read from the flow meter to ensure consistency in readings. If the difference between the flow meter and the bucket and stopwatch estimation was within 5 percent, the flow meter was considered accurate.

4.2.4.2 Laboratory Quality Control Program

PRI completed all the laboratory tests listed in Table 4-2 to characterize the cover materials at each site and to compare the MatCon™ cover with the conventional asphalt cover at the DAFB site. In conjunction with these physical testing procedures, PRI routinely performed a number of QC checks that are detailed in the QAPP (Tetra Tech 2000).

Calibration of the test equipment was performed, where required, and records maintained at PRI. For the air voids and binder property measurement, standard AASHTO specimens were used. Results obtained were within two standard deviations of the mean published by the Asphalt Materials Reference Library (AMRL) proficiency standard samples. The AMRL is maintained by the National Institute of Standards. Except for the shear test data, all other test data were within the acceptance criteria detailed in the QAPP. Due to equipment malfunction at the Auburn University laboratory (PRI's subcontractor), the shear test data were unacceptable.

Laboratory data were checked regularly for consistency with the expected result. For example, when the laboratory permeability results of the MatCon™ samples were significantly greater (greater than 1 x 10^{-6} cm/sec) than the expected value of 1 x 10^{-8} cm/sec, analyses of the air void percentage of the samples were found to be higher than the expected value of 3 percent. Air void percentage is a primary factor in the performance of the MatCon cover. In a real-world landfill cover application project, void percentages of greater than 3 percent would warrant the re-installation of the cover. Therefore, for the purposes of this demonstration, additional cores were obtained from the MatCon™ slab sample and analyzed for air void percentage. Based on these results, a re-analysis of permeability was conducted on core samples with 3 percent or less air void percentage. These results are presented in Section 3.0.

4.3 SITE Demonstration Results and Conclusions

The results of the evaluation are presented below in relation to the primary and secondary objectives established for the evaluation in the TEP/QAPP. Primary (P) objectives are considered critical for the technology evaluation, and secondary (S) objectives provide additional useful information.

P1--Determine if the MatCon™ cover exhibits a field permeability of less than the RCRA Subtitle C requirement of 10^{-7} centimeters per second (cm/sec).

To estimate the field permeability of the MatCon™ cover, the volume of infiltration during individual rainfall events was measured over the 6-month demonstration period at each of the two sites. Using Darcy's Law, the measured infiltration rates were converted into estimates of field permeability, and these estimates were compared to the regulatory requirement.

The in-field permeability calculated from measured infiltration for the MatCon™ covers at the DAFB and TCL sites is provided in Table 4-3. The table indicates that the in-field permeabilities are up to 3 orders of magnitude lower than the requirement for RCRA Subtitle C landfill covers.

P2--Compare the laboratory-measured permeability and flexural properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site.

The vendor claims that the MatCon™ cover is both less permeable and has superior flexural properties when compared to conventional asphalt. To test these claims, laboratory tests that evaluate the two properties were conducted on both MatCon™ and conventional asphalt samples from the DAFB site. Results for each parameter were then compared using descriptive statistics to determine whether the MatCon™ cover appears to be superior to conventional asphalt for these two critical parameters.

Table 4-4 provides a summary of the laboratory properties of MatCon™ and conventional asphalt. As shown in this table, the average permeability of MatCon™ was about four orders of magnitude lower than that of conventional asphalt. The flexural tests of the MatCon™ cover samples indicate that a 36-inch-long (91.4-cm) beam can sustain 20.41 millimeters of deflection without cracking, whereas conventional asphalt cracked at 7 to 10 millimeters of deflection. Further, the MatCon™ cover sample had no cracks under 20 millimeter of deflection, whereas the conventional asphalt had 3-millimeter-wide, 2.5-cm-long cracks at about 25 millimeter of deflection.

S1--Measure other laboratory-measured physical properties of the MatCon™ cover and the conventional asphalt cover at the DAFB site

The vendor makes no specific claim for the superiority of MatCon™ to conventional asphalt with respect to physical parameters other than permeability and flexural properties. However, differences in other physical properties that can be measured in the laboratory may be of interest to potential users. Therefore, samples of both the MatCon™ cover and the conventional cover were taken

Table 4-3. Estimated In-Field Permeability of MatCon™ Cover During Rainfall Events*

Period Ending	Measured Leakage Volume (m^3)	Calculated Permeability (cm/sec)
Dover Air Force Base		
07-Apr-00	3.3E-02	4.5E-08
17-Apr-00	6.4E-03	1.3E-08
27-Apr-00	6.2E-02	1.3E-07
09-May-00	6.4E-03	2.6E-08
16-May-00	6.3E-02	1.3E-08
26-May-00	6.3E-02	8.5E-08
09-Jun-00	6.3E-02	8.5E-08
Tri-County Landfill		
20-May-00	2.8E-03	1.9E-09
02-Jun-00	5.9E-04	5.2E-10
7-Jul-00	2.7E-03	3.4E-09
21-Jul-00	9.4E-03	1.5E-08

* At each site, a ponding test was also conducted to measure in-field permeability.

Table 4-4. Statistical Summary of Laboratory Data.

Parameter	MatCon™ Asphalt					Conventional Asphalt				
	No. of Samples	Mean	Std. Dev.	Min.	Max.	No. of Samples	Mean	Std. Dev.	Min.	Max
Tri County Landfill (TCL) Void Space, %	4	1.55	0.87	0.25	2.1	–	–	–	–	--
TCL Hydraulic Conductivity (cores) cm/sec	7	≤1.0 x 10^{-8}	0^2	≤1.0 x 10^{-8}	≤1.0 x 10^{-8}	–	–	–	–	--
Dover Air Force Base (DAFB) Hydraulic Conductivity (cores)	4	≤1.0 x 10^{-8}	0^2	≤1.0 x 10^{-8}	≤1.0 x 10^{-8}	3	1.04 x 10^{-4}	1.5 x 10^{-4}	1.8 x 10^{-5}	2.75 x 10^{-4}
Flexural Properties at Center, Deflection in mm	2	18.96	2.08	17.51	20.41	2	31.25	7.54	25.92	36.58
Joint Integrity cm/sec	3	5.47 x 10^{-5}	2.02 x 10^{-5}	4.3 x 10^{-5}	7.5 x 10^{-5}	3	1.04 x 10^{-4}	1.5 x 10^{-4}	1.8 x 10^{-5}	2.75 10^{-4}
Conductivity after Accelerated Weathering 30 days, cm/sec	3	7.35 x 10^{-9}	6.05 x 10^{-9}	1.65 x 10^{-9}	1.37 x 10^{-8}	3	2.96 x 10^{-4}	2.89 x 10^{-4}	2.65 x 10^{-4}	3.22 10^{-4}
Conductivity after Accelerated Weathering 60 days, cm/sec	3	2.2 x 10^{-6}	3.8 x 10^{-6}	3.9 x 10^{-9}	6.6 x 10^{-6}	3	3.15 x 10^{-4}	1.32 x 10^{-4}	1.77 x 10^{-4}	4.41 x 10^{-4}
Fuel Resistance (Kerosene) Depth of Penetration, cm	8	1.5	0	1.5	1.5	8	5.5	0.53	5	6

Table 4-4. Statistical Summary of Laboratory Data (continued).

Parameter	MatCon™ Asphalt					Conventional Asphalt				
	No. of Samples	Mean	Std. Dev.	Min.	Max	No. of Samples	Mean	Std. Dev.	Min.	Max.
DAFB Void Space, %	4	1.53	0.33	1.25	1.89	6	10.53	1.17	9.2	12.7
Coarse Aggregate Specific Gravity	3	2.74	0.01	2.73	2.75	3	2.75	0.03	2.72	2.78
Fine Aggregate Specific Gravity	3	2.72	0.01	2.71	2.72	3	2.74	0.01	2.73	2.74

from the DAFB site and analyzed for various parameters pertinent to the physical performance of asphalt paving and covers. Results for each parameter were then compared using descriptive statistics to determine if there are any significant differences between the two types of covers.

The physical properties measured to satisfy objective S1 are listed below:

- Joint integrity
- Load capacity and deformation
- Shear strength
- Tensile strength
- Thermal crack resistance
- Aging and degradation properties
- Void space
- Aggregate properties

S2--Determine whether extreme weather conditions or vehicle loads affect the field performance of the MatCon™ cover

To evaluate this objective, the MatCon™ covers at both sites were inspected periodically in the field, particularly following periods of extreme cold or other adverse weather conditions, to assess whether any cracks or surface deformities developed. These field inspections were used to evaluate the effects of extreme weather or vehicle loads since the previous inspection. General information on use of the covers for parking and on recent weather events was collected from the site owners and evaluated against any deformities noted in the field inspections. The TCL site in Elgin, Illinois, encountered much colder temperatures than the DAFB site in Dover, Delaware. As a result, data on the impacts of extreme cold were observed only at the TCL site.

At the TCL site, WMI parked their garbage trucks during the night and their waste recycling trucks traveled over the MatCon™ cover during the day. Further, the MatCon™ cover was subjected to extremely cold, sub-zero weather during January through March 2000. In late January, a crack was observed on the cover surface. This was investigated by taking core samples at the crack location and obtaining nuclear density measurements in the vicinity of the crack. Except for the core sample on the crack that had developed at a cold joint, all samples showed a permeability in the range of 10^{-7} cm/sec to 10^{-9} cm/sec. The sample on the crack had 8.2 percent air voids and a permeability of 3.56×10^{-5} cm/sec, indicating it was poorly compacted due to inadequate field quality control.

Based on the investigation, WCC improved the design and construction procedures for cold joint construction for MatCon™ covers. The crack was repaired by routing the joint, cleaning the joint using a hot air lance, and extruding it full of hot modified asphalt mastic joint sealer. Apart from the crack that developed at the cold joint, the rest of the MatCon™ cover performed well under extreme weather conditions and vehicle loads.

S3--Estimate a cumulative hydrologic balance for the MatCon™ cover over the period of the demonstration at the DAFB site

A hydrologic balance for the cover system was estimated at the DAFB site. The hydrologic balance was based on cumulative precipitation, totalized surface runoff, and subsurface drainage over the entire 6-month demonstration period. Although the hydrologic balance is approximate because of the length of time involved, it may provide additional insights into the performance of the MatCon™ cover.

Theoretically, the infiltration into the MatCon™ cover could be determined by using the equation
$I = P - ET - Qs$, where

I = Infiltration

P = Precipitation volume

ET = Evapotranspiration from the MatCon™ surface

Qs = Runoff

However, heavy precipitation events resulted in flooding and precluded accurate measurement of surface runoff. Therefore, a hydrologic balance for the DAFB site could not be obtained in this manner.

S4--Estimate the cost for constructing the MatCon™ cover and maintaining the cover for the duration of the demonstration

The capital and operating costs for the MatCon™ cover technology, as demonstrated at both the DAFB and TCL sites, were estimated based on cost information obtained from WCC and reviewed by Tetra Tech. The costs of the MatCon™ installation are detailed in Section 3.0 of this report.

4.4 Discussion of Results

A discussion of the field and laboratory measurements affecting MatCon™ performance is provided below.

4.4.1 Discussion of Field Data

The measured field permeability varied from a high value of 1.28×10^{-7} cm/sec to a low value of 5.15×10^{-10} cm/sec. The field permeability data calculations were based on several assumptions and Darcy's law. The uncertainties in the calculations included the following.

- The head was based on measured precipitation over the entire site; however, the MatCon™ surface was not subjected to the uniform head assumed for the precipitation event. Most of the precipitation did not remain on the surface, except for the two ponding tests.
- Infiltration measured as water volume in the sump does not account for changes in the water retained in the drainage layer.
- There was uncertainty at the DAFB site about the measurement of infiltration into the drainage layer. The high groundwater table at the site resulted in flooding, and there is a possibility that water infiltrated through the sidewalls of the sump.

To minimize uncertainties, a ponding test was then conducted at the TCL site during a 48-hour period. Oversight was provided by COE and EPA personnel. This resulted in a measured permeability value of 5×10^{-8} cm/sec. This value is higher than that obtained during rainfall events probably because during rainfall events a consistent hydraulic head is not maintained. The water head was maintained on the MatCon™ surface more consistently during the ponding test. The ponding test at the DAFB site yielded a result of 1.25×10^{-8} cm/sec.

4.4.2 Laboratory Data

The laboratory data presented in Table 4-4 and elaborated in this section provide a comparison of MatCon™ and conventional asphalt. As discussed in Sections 4.4.1 and 4.4.2, the primary physical properties that were studied included permeability and flexural properties, and the secondary physical properties that were measured included thermal crack resistance, load capacity and deformation, tensile strength, and aging and degradation properties. These properties are discussed below.

4.4.2.1 Permeability

Permeability is a critical parameter determining the performance of the MatCon™ cover. Table 4-4 indicates that the laboratory permeability of MatCon™ is about four orders of magnitude lower than conventional asphalt, and is less than 1 x 10^{-8} cm/sec. This is due to the lower void space and higher density of MatCon™ compared to conventional asphalt.

4.4.2.2 Flexural Properties

The ability of MatCon™ to settle over potential voids in the underlying materials isan important characteristic when considering caps over fills associated with waste materials. Most traditional tests for highway engineering do not consider flexural behavior that can occur with high strains in these settings. Consequently, a specialized test was used in this study to consider large strains.

Comparative data for MatCon™ and conventional asphalt are presented in Figure 4-11. This figure illustrates the total deflection versus time with notes indicating the onset of cracking. In all cases, the conventional material started cracking before the total deflection reached 15 millimeters, while the MatCon™ did not crack even at deflections as large as 20 millimeters. This increase in strain tolerance is attributed to the improved binder that is used in the MatCon™ system. The data collected demonstrate that MatCon™ is able to experience larger strains and deflections than conventional asphalt without cracking.

4.4.2.3 Load Capacity and Deformation

Introducing a loading stress, such as the weight of a vehicle, causes strains in the asphalt structure. These strains can lead to premature failure if the structure is not designed adequately. Two modes of failure are generally considered for the design of asphalt structures, which are dependent upon the resilient properties of the materials: (1) fatigue failure is dependent on resilient modulus/stiffness and fatigue properties of the materials and (2) permanent deformation, which is controlled by the aggregate interlock and high temperature properties of the binder.

Load capacity is determined by assessment of the resilient modulus over a range of conditions, and the permanent deformation behavior is measured with shear testing.

The resilient modulus was measured for temperatures ranging from -20 °C to +80 °C. The modulus of MatCon™ was 2048 MPa compared to 3200 MPa for the conventional asphalt. The reduced resilient modulus of the MatCon™ was due to the use of a modified binder that is more flexible at the lower temperatures applied in the resilient modulus test. However, at higher temperatures, the modulus of the MatCon™ exceeded that for conventional asphalt. This indicates that MatCon™ performs acceptably over a wider range of temperatures than conventional asphalt for distress modes such as cracking (at lower temperatures) and permanent deformation and rutting (at higher temperatures).

4.4.2.4 Tensile Strength

Tensile strength affects cracking due to thermal- or load-related effects. The tensile strength of asphalt materials varies with temperature, time of loading, and magnitude of strain. High stiffness materials are subjected to more stress at lower temperatures, and hence can be more susceptible to cracking.

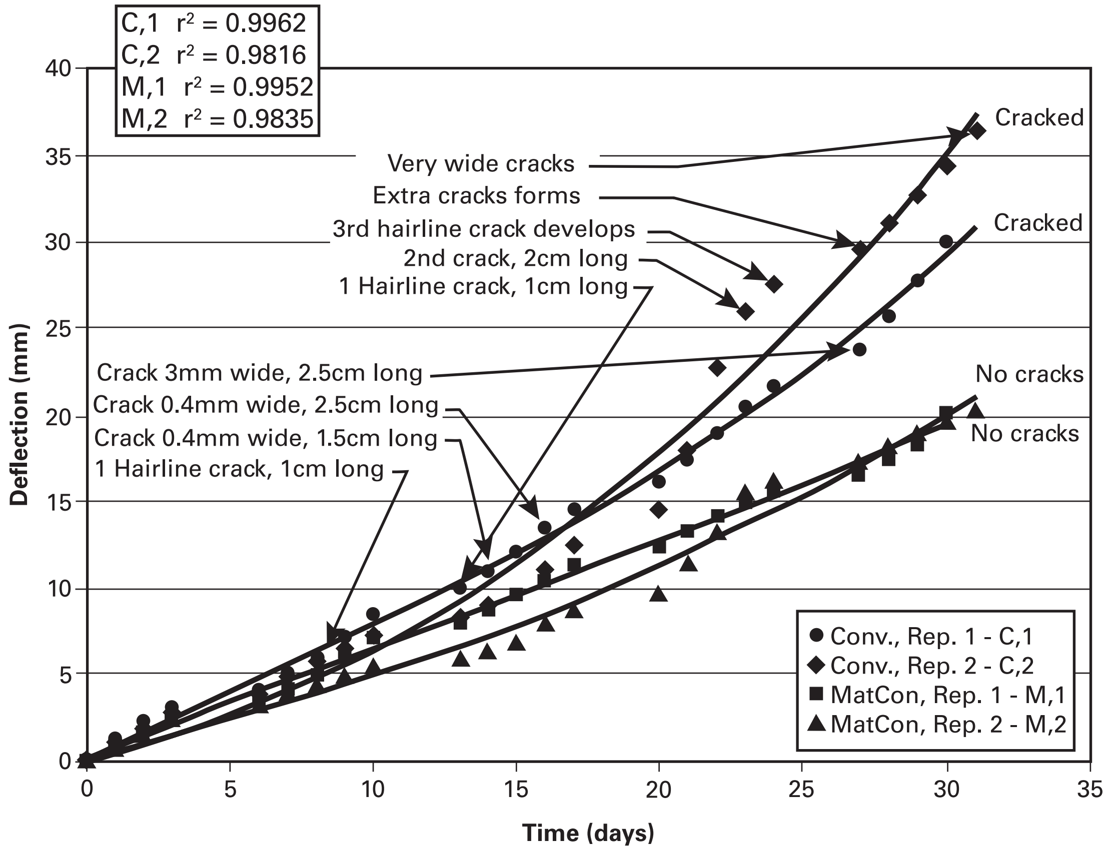
The low temperature tensile properties of MatCon™ and conventional asphalt are shown in Table 4-5. The data show that the tensile strength of the MatCon™ material is approximately 50 percent greater than for conventional asphalt, and that the expected cracking temperature is approximately 5 to 7 °C lower.

The tensile properties of MatCon™ indicate that it should be more resistant to the formation of cracks over the range of temperatures anticipated in a landfill surface cover. Of particular importance is the low-temperature tensile properties, since asphalt materials generally crack at these temperature extremes. At low temperatures, MatCon's™ tensile properties enable it to be used in significantly harsher climatic regions without the risk of cracking.

4.4.2.5 Thermal Crack Resistance

As asphalt materials cool, the natural tendency is for the material to attempt to contract as a function of the coefficient of thermal expansion. However, the contraction is effectively prevented by the structure; consequently, thermal stress builds in the asphaltic material as the temperature drops. The increase in thermal stress eventually results in fracture if the tensile strength of the material is exceeded.

The asphalt binder choice has the most significant impact on thermal crack resistance. Other factors, such as aggregate choice and subgrade type, affect the density and degree of cracking after cracks have started.



Source: PRI Asphalt Technologies, Inc. 2000.

Figure 4-11. Curves showing deflection versus time.

Table 4-5. Tensile Properties for Binder and Mixture at Cold Temperatures

	Tensile Properties Derived from Tests On:			
Property	Binder		Mixture	
	Conventional Asphalt	MatCon™	Conventional Asphalt	MatCon™
Tensile Strength (MPa)	1.86	2.97	2.579	3.551
Fracture Temperature (°C)	-18.8	-25.7	-25.4	-29.7

The results obtained are presented in Figure 4-12. The MatCon™ samples had a higher fracture strength (by 37 percent) and a 4.3 °C lower fracture temperature than conventional asphalt. The test results indicate that MatCon™ has improved low temperature behavior and will resist thermal cracking better than conventional asphalt. The degree of improvement in both fracture strength and temperature is attributed to the modified binder.

4.4.2.6 Aging and Degradation Properties

Aging of asphalt materials is caused by several chemical and physical processes, especially oxidation and volatilization. Volatilization is the loss of lighter molecular weight fractions through evaporation that begins with distillation of crude oil. Removal of lighter fuel oils leaves heavier residue, including asphalt. Further refining and processing results in a stable base asphalt cement that is then engineered for various uses, such as paving and roofing. The quality of asphalt is governed largely by the source of crude oil, and the only sources used for MatCon™ are those in which long term stability and further volatilization are minimized. These properties are evaluated using standardized test protocols. The mass loss of volatile material in a standard laboratory test is almost immeasurable for high quality asphalt and is essentially nil over the multi-year life expectancy of pavements.

For very dense, low void MatCon™ mixtures made with modified asphalt, the expectation is for longevity much greater than for conventional pavements. Several factors contribute to this expectation, including the use of base asphalt that was selected for superior aging characteristics, use of modifiers that chemically enhance resistance to degradation, and the low voids that prevent intrusion of air and water. The accelerated weathering tests used in this study were adapted from the roofing industry, in particular the International Conference of Building Officials (ICBO), which typically attempts to predict performance of asphalt roofing materials. However, any attempt to predict the actual service life of MatCon™ based on this testing would be speculative because of the many variables and the heretofore unknown performance of MatCon.™ The approach used in this study is to compare the behavior between MatCon™ and conventional pavement on a relative basis, both in the laboratory and by monitoring field performance over several years.

The aging of asphalt materials is affected by a number of parameters such as binder quality, mixture type, and climate. However, if a system is made effectively impermeable, the supply of oxygen needed to age-harden the binder is effectively restricted. MatCon™ materials are designed to achieve a low permeability and consequently, aging is anticipated to be low. For all conditions tested, the resilient modulus of the MatCon™ does not exceed that of the conventional asphalt. The low void space and higher binder content in MatCon™ results in the better aging properties observed for MatCon™ compared to conventional asphalt.

Accelerated aging provides an insight into how MatCon™ asphalt will perform over its expected life. The accelerated aging test method is used to determine changes in asphalt material and performance properties after 30 and 60 days of exposure to cycles of ultraviolet light and water sprays. In the accelerated aging study, the slab sections were placed in an accelerated weathering chamber and left exposed to cyclic ultraviolet light (20 hrs) and water sprays (3.5 hrs) with a surface temperature of approximately 160 °F. After 30 and 60 days, specimens were evaluated for changes in binder properties due to ultraviolet light and water exposure.

Results of binder property changes were reported as a PG rating, which is the performance window of the asphalt between a high and low temperature that the binder is expected to perform without cracking. The PG rating is the key component for long-term performance at the high service temperature for properties indicative of a susceptibility to deformation, such as rutting, and at the low service temperature for properties that forecast a susceptibility to fatigue and thermal cracking. A grading system for asphalt was developed by the highway industry and has been adapted by AS™ (AS™ D-6373).

The accelerated aging tests indicated that the MatCon™ binder was essentially unaffected by exposure to ultraviolet light, maintaining the same performance grade, PG 82-22, after 60 days of aging, whereas the conventional asphalt binder lost both high and low temperature performance grades upon exposure, going from the initial PG 82-22 to PG 76-16 after 60 days of accelerated aging. The change in PG rating of the conventional binder indicates the binder has lost stiffness and elastic modulus at high temperatures and flexibility and pliability at low temperatures. The loss at low temperature is also indicative of a binder's aging rate.

Review of the binder properties after exposure to cyclic water sprays shows the MatCon™ binder has a wider performance grade, PG 88-21 (109 °C), than

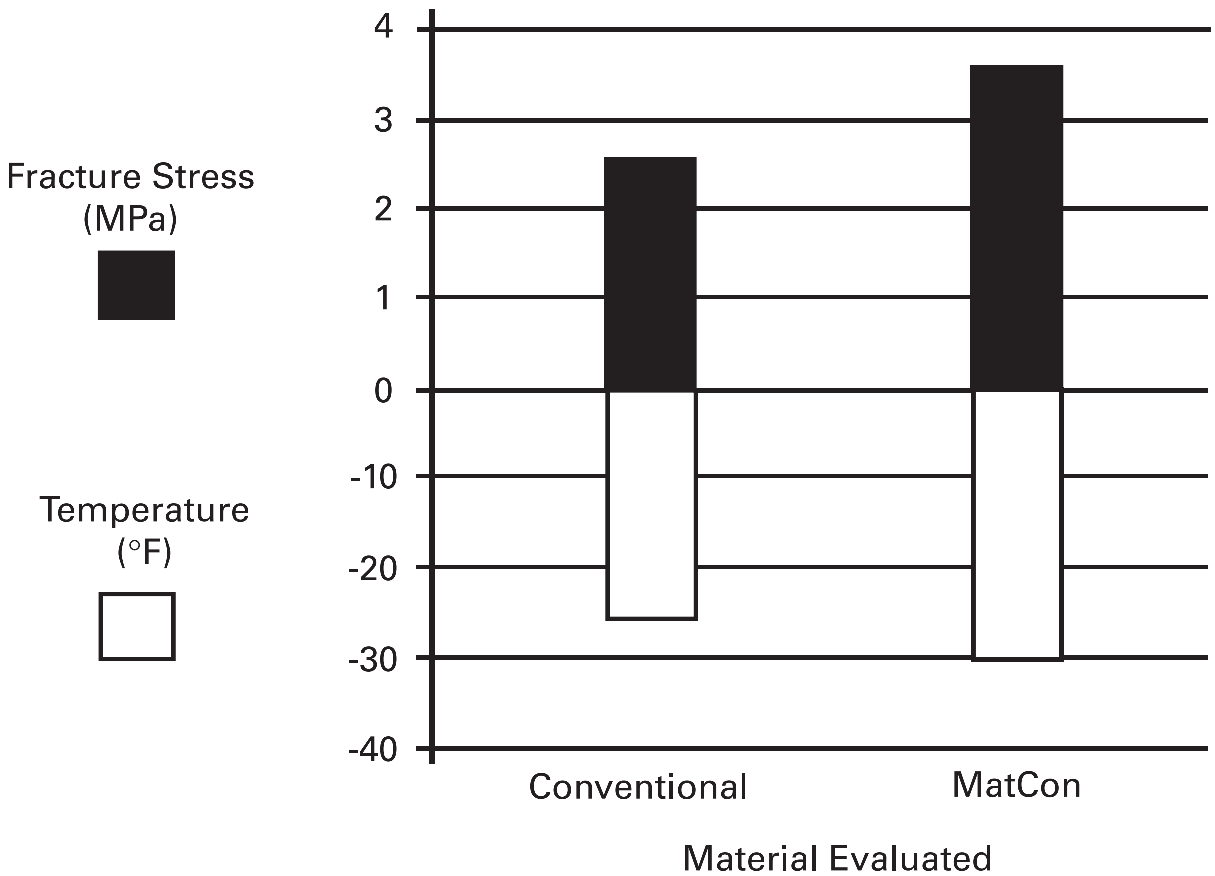


Figure 4-12. Fracture stress (MPa) and temperature (°C) for MatCon™ and conventional material.

the conventional binder, PG 82-19 (101 °C). The low temperature properties after aging also indicate that the MatCon™ binder has an improved resistance to low temperature thermal cracking. A top to bottom profile comparison indicated that the exposure to water had minimal effect on the binder properties.

As seen from the data presented in Table 4-4, the permeability of the conventional cover remained generally unchanged after accelerated aging. The permeability of the MatCon™ cover increased by an average of two orders of magnitude, but remained one to two orders of magnitude lower than that of the conventional cover. The degradation of the MatCon™ after continued exposure to kerosene was 1.5 cm (out of a total 10-cm thickness). Under similar conditions, conventional asphalt degraded by an average of 5.5 cm (out of a total of 10-cm thickness).

Section 5
Technology Status

This section of the report describes commercial availability and quality control requirements for the MatCon™ technology.

5.1 Commercial Availability

The first MatCon™ cover over incinerator fly ash was installed in Ferndale, Washington, in 1989. This cover maintains low permeability (less than 10-8 cm/sec) after 12 years of active use as a surface for material staging and heavy equipment operation. Since then, MatCon™ has been approved by state regulating agencies for projects in Delaware, Illinois, California, Florida, Texas, New Mexico, and Kentucky, the states where it has been presented by WCC.

The proprietary binder available from WCC can be shipped to any hot mix asphalt plant in the country. The MatCon™ mix is prepared at the hot mix plant under the strict QC specifications provided by WCC. Therefore, MatCon™ technology is commercially available throughout the United States.

5.2 Construction Quality Assurance Requirements

Based on the TCL project findings, the key areas requiring special attention during future MatCon™ installations are described below.

- Adequate scheduling to allow for input on subgrade design, followed by planning and coordination for subsequent in-field construction progression
- Subgrade construction and preparation to ensure firm and unyielding conditions that will allow for proper MatCon™ compaction and facilitate proper drainage from the final MatCon™ surface
- Monitoring MatCon™ hot-mix temperatures prior to installation for material acceptance or rejection
- Hourly in-field inspection and acceptance or rejection of compacted MatCon™ based upon frequent and mapped field density measurements
- Construction and workmanship of cold joint panels assuring compaction and sealing
- Design, construction, and workmanship of any leak detection or lysimeter structures
- Provisions for quality control inspection technicians to monitor, inspect, report, and either accept or reject: subgrade conditions prior to paving; lysimeter or leak detection systems; MatCon™ hot-mix plant operations; MatCon™ hot-mix transfer and paving activities; MatCon™ panel compaction and resultant field densities; and cold joint construction methods and sequences

Section 6
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