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Evaluation of the Effectiveness Of Drainage Layers

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16. Abstract

Research has shown that pavement subdrainage systems can increase the life of pavements by removing water that is detrimental to the pavement structure. The Mississippi Department of Transportation (MDOT) began including pavement subdrainage systems in the construction of major highways in the mid to late 1990's. The objectives of this study were to evaluate the performance of current MDOT subdrainage systems and to evaluate maintenance procedures and inspection schedules for existing edge drains and outlets. Research findings show the subsurface drainage systems instrumented in this study to be functioning efficiently. Research findings also indicate that no statewide inspection or maintenance schedules for pavement subdrainage systems are currently being followed by MDOT maintenance personnel.

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CHAPTER I

INTRODUCTION

Background

Highway pavements are traditionally constructed on low permeable subgrades and within low permeable shoulders. These features trap water within the pavement structure. Pavements constructed in this manner are termed “box,” “trench,” or “bathtub” sections. (1) The presence of free water in any pavement structure, whether flexible or rigid, has detrimental effects on the pavements performance. If an efficient pavement subdrainage system is provided, the water can be effectively drained from the pavement structure, increasing the pavements life and reducing maintenance. With this in mind the Mississippi Department of Transportation (MDOT) began incorporating pavement subdrainage systems in construction of major highways in the mid to late 1990’s.

Objectives

Research objectives of this study were:

1. Conduct a field study to evaluate performance of existing pavement subdrainage systems.

2. Review MDOT’s current standards, specifications, and design guidelines for drainage layers and pipe collector systems.
3. Suggest revisions for standards and specifications from analysis of field data.
4. Recommend maintenance procedures and schedules for existing edge drains and outlets.

Scope

Two pavement sections were selected for instrumentation in this study. Selected pavement sections consisted of a newly constructed concrete pavement and a newly constructed asphalt pavement.

Work began by obtaining and/or constructing necessary instrumentation. After construction and calibration of instrumentation, each section was instrumented to collect rainfall and outflow data. Data for each section was analyzed to determine how effectively each was performing.

A literature review was performed as part of this study along with a review of MDOT’s current standards and specifications for drainage layers and pipe collector systems. Literature was also reviewed in an effort to develop maintenance procedures and schedules for existing subdrainage systems in Mississippi.

CHAPTER II

LITERATURE REVIEW

Effects of Water

The presence of free water can have detrimental effects on pavements and their foundations. Huang (2) summarized detrimental effects of free water as follows:

1. It can reduce strength of unbounded granular material and subgrade soil.
2. It causes pumping in concrete pavements, which leads to faulting, cracking, and shoulder deterioration.
3. Heavy wheel loads can cause pumping of fines in the base course of flexible pavements, leading to a loss of support.
4. In frost susceptible regions, a high water table can cause frost heave and a reduction of load bearing capacity during frost melting periods.
5. Water causes differential heaving of swelling soils (fat clays).
6. Water, in conjunction with other factors such as dusty aggregate, excess mineral filler, uncrushed aggregate, and low asphalt content, can lead to stripping of asphalt in flexible pavements. (3)
7. Free water can induce durability cracking of rigid pavements.

The detrimental effects of water were evident in two major road tests. Those were the WASHO road test in Idaho and the AASHO road test in Ottawa, Illinois. Cedergren noted that these tests "proved conclusively that free water in structural sections accelerated damage rates hundreds of times over the damage rates with no free water present". Despite this knowledge, internal pavement subdrainage systems were ignored as a better way to design pavements. Most pavement designers at that time falsely believed making pavements thicker and stronger would be sufficient. (1)

Pavement Subdrainage System

A typical pavement subdrainage system should be constructed with the following:

1. A highly permeable, open graded drainage layer (OGDL)
2. An impervious "filter" or "separator" subbase layer beneath the OGDL
3. A longitudinal collector system consisting of:
    - Collector trench
    - Perforated pipe
    - Aggregate backfill
    - Fabric
4. Marked outlet pipes

Open Graded Drainage Layer

A highly permeable OGDL allows infiltrated water to drain into the longitudinal collector system and out of the pavement structure. Aggregate gradations of OGDL's vary and aggregate may be treated untreated or treated with Portland or asphalt cement. Treatment of aggregate stabilizes the drainage layer and aids in constructability. The Ontario Ministry of Transportation typically adds 1.8 percent asphalt cement (AC) to ensure constructability of OGDL's (4). An asphalt treated OGDL, as constructed on US 45 Alternate in Lowndes Co. (MS), is shown in Figure 2.1 below.

Figure 2.1 Asphalt Treated OGDL (US 45 Alt. Lowndes Co.)

Subbase Layer

An impervious subbase layer is needed to filter or separate the OGDL form the subgrade soil. Without this layer, the large open graded aggregate could be forced into the subgrade under heavy wheel loads, introducing subgrade material into the drainage layer. Introduction of fine-grained materials into the drainage layer could cause clogging, lowering its permeability, and decreasing the effectiveness of the drainage system. A filter layer can be constructed of a dense aggregate subbase or it can be accomplished using a geotextile fabric or membrane.

Longitudinal Collector System

A longitudinal collector system intercepts free water flowing from the OGDL. Roadway sections containing a normal crown should have longitudinal collector systems along both sides of the roadway. When superelevations are present; longitudinal collectors must only be located on the low end. To construct a longitudinal collector system, trenches should first be cut along the roadway edge. These trenches should contain a perforated pipe that will collect free water and remove it from the pavement structure. Perforated pipes should be covered with aggregate and wrapped with fabric that will act as filter material to prevent the pipe from becoming clogged. Figure 2.2 shows a longitudinal collector system as built on US 45 Alternate in Lowndes Co. (MS). The figure shows a fabric lined trench with an aggregate covering the unseen perforated pipe.

Figure 2.2 Longitudinal Collector Trench (US 45 Alt. Lowndes Co.)

Outlet Pipes

Outlet pipes should be installed at an appropriate spacing to discharge water from the pavement structure. AASHTO guidelines suggest that outlets for longitudinal edgedrains not contain spacing greater than 300 meters (5). Many states including Wisconsin and Illinois use an outlet spacing of approximately 250 feet. This spacing is specified based on the need for inspection and cleaning equipment to adequately traverse the entire edge drain system. It is possible for outlets to be spaced at greater lengths if clean out ports are located at the midpoint between outlets.

Outlet pipes are constructed with concrete headwalls or splash blocks to prevent erosion around the outlet. Metal screens are also inserted into the pipes to prevent rodents and other small animals from clogging the outlets with nests and other debris. Figure 2.3 shows a concrete outlet headwall with two outlet pipes as constructed on MS 25 in Atalla County. The purpose of double outlet pipes in Mississippi is given in a discussion of Mississippi's edge drain systems later in this chapter.

Outlet Markers

Some form of marker should be provided for each outlet. Markers are used for easy identification of outlet locations for maintenance and inspection crews. Common markers include signs on fences, reflector discs in the shoulder, or painted arrows on the shoulder (6). A piece of white tape serves as an outlet marker along the edge of pavement in Figure 2.3. Maintenance engineers in Mississippi have expressed a desire to have outlets marked with GPS co-ordinates. Maintenance crews are already provided handheld GPS units and could easily identify outlet locations for maintenance purposes.

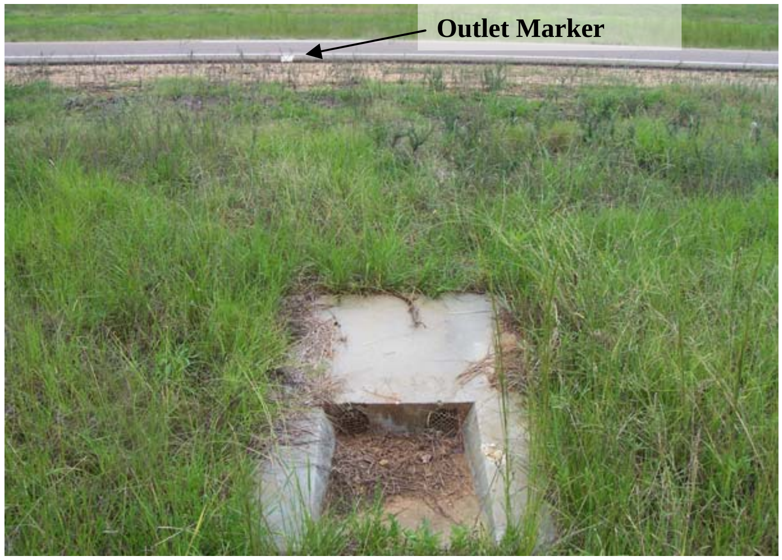

Figure 2.3   Concrete Headwall and Outlet Marker

AASHTO Considerations

AASHTO recognized the positive effects of internal drainage and addressed the problem within updated pavement design guides. The 1986 AASHTO design guide for both flexible and rigid pavements included a new factor in the structural number equation that was not included in the 1972 design guide. The m factor for flexible pavements and the c_d factor for rigid pavements were added to account for environmental factors and quality of pavement drainage. The m factor and the c_d factor can be found in Table 2.1 and Table 2.2, respectively.

Table 2.1 Recommended m Values for Flexible Pavements (7)

Quality of Drainage	Percent of Time Pavement Structure is Exposed To Moisture Levels Approaching Saturation			
	Less than 1%	1-5%	5-25%	Greater than 25%
Excellent	1.40-1.35	1.35-1.30	1.30-1.20	1.20
Good	1.35-1.25	1.25-1.15	1.15-1.00	1.00
Fair	1.25-1.15	1.15-1.05	1.00-0.80	0.80
Poor	1.15-1.05	1.05-0.80	0.80-0.60	0.60
Very Poor	1.05-0.95	0.95-0.75	0.75-0.40	0.40

Table 2.2 Recommended C_d Values for Rigid Pavements (7)

Quality of Drainage	Percent of Time Pavement Structure is Exposed To Moisture Levels Approaching Saturation			
	Less than 1%	1-5%	5-25%	Greater than 25%
Excellent	1.25-1.20	1.20-1.15	1.15-1.10	1.10
Good	1.20-1.15	1.15-1.10	1.10-1.00	1.00
Fair	1.15-1.10	1.10-1.00	1.00-0.90	0.90
Poor	1.10-1.00	1.00-0.90	0.90-0.80	0.80
Very Poor	1.00-0.90	0.90-0.80	0.80-0.70	0.70

Although the factors are numerically different for flexible and rigid pavements, they address the same principal. The design rewards good drainage and shorter exposure time. Factors greater than one lead to a decreased overall pavement thickness and factors lower than one, lead to a thicker pavement.

The quality of drainage is left to the discretion of the design engineer to determine. AASHTO does provide general recommendations that correspond to different drainage times for pavements. These recommendations are shown below in Table 2.3.

Table 2.3 AASHTO Quality of Drainage Recommendations (7)

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very Poor	Water will not drain

Subdrainage Research

Research studies have been conducted in the laboratory and the field to assess the benefits of pavement subdrainage systems. Benefits can be considered many different ways including moisture content, strength (subgrade modulus), precipitation vs. outflow, time to drain, and cost.

Precipitation vs. Outflow and Time to Drain

Both Ahmed (8) and Hassan (9) evaluated precipitation vs. outflow as a measure of performance on Indiana subdrainage systems. Using rain gauges and outflow measuring devices; rainfall events were evaluated by the total volume of rainfall versus the measured volume of outflow provided by the edgedrains. Hassan originally termed this ratio as "efficiency" but later concluded that efficiency is better indicated by the AASHTO time to drain recommendations.

Kazmierowski et al. (4) took a more direct approach when evaluating drainage effectiveness of OGDL's in Ontario. Their field evaluation was done by introducing a controlled amount of water into the OGDL through a hole cored through the pavement surface to the top of the drainage layer. The time to drain and volume of discharge were recorded at the downstream outlet. Using the known volume introduced and the volume of outflow measured; percentage of infiltrated water drained could be calculated. This process was repeated with an increased flow of water to demonstrate how time to drain was affected by infiltration rate.

Strength and Moisture Content

Fleckenstein et al. (10) performed falling weight deflectometer (FWD) tests in Kentucky in an effort to compare the subgrade modulus of a pavement section before and after installation of pavement edgedrains. Results of FWD testing showed that two years after installation of edgedrains, the subgrade modulus for the pavement section had increased by 64%. Soil samples were obtained from pavement sections with and without pavement edgedrains. From these samples, normalized subgrade moisture content was determined. The results showed the normalized subgrade moisture is approximately 28 percent lower for sites with edgedrains than it is for sites without edgedrains.

Cost

Moisture content has been proven to have dramatic effects on the life of a pavement. A study in New Jersey by Zaghloul et al. (11) looked at the effect on service life and cost savings due to lower moisture content as a result of a pavement section having a daylighted base. The study provided that increasing the base course moisture content from 16% to 45% would result in a decrease in pavement service life from 13 years to 7 years. It was concluded that substantial long-term savings could be achieved by increasing the subsurface drainage of flexible pavements, noting that use of full subsurface drainage systems could enhance performance even greater than that seen in this study.

Maintenance

The most significant issue with internal drainage systems is maintaining them. If not properly maintained, drainage systems can become ineffective and detrimental to the pavement structure. The FHWA (12) went as far as to say that, "If a State Highway Agency (SHA) is unwilling to make a maintenance commitment, permeable bases should not be used since the pavement section will become flooded. This increases the rate of pavement damage."

Many maintenance issues can affect the drainage system performance. Vegetation, sedimentation, and erosion around the outlet pipe can reduce the overall system effectiveness. Also, many drainage systems are damaged during their construction, which makes them ineffective from the start.

Maintenance problems are unfortunately common with internal drainage systems, but they are easily addressable. Erosion around the outlet pipe is reduced by constructing a concrete headwall or splash pad at the outlet pipe. This helps to diffuse water and subsequently reduce soil erosion near the outlet pipe.

Sedimentation can occur in the longitudinal edge drains that collect the water from the pavement structure. Such sedimentation can be reduced if the drain trench is backfilled with the correct filter material to prevent the transport of fines. Some sediment will still build up in the pipes with time. FHWA studies suggest that periodic flushing or jet rodding of the pipes will effectively remove this sediment (12).

Special care should be taken during the construction of drainage layers, especially around the outlet pipes. Outlet pipes are located along the pavement shoulders. Installation of outlets occurs before final grades are set on the slopes. Outlets can be easily crushed by bulldozers and motor-graders during the finish grading process. To prevent this, outlets should be clearly marked so that construction traffic can avoid them. Special care should also be used when laying the longitudinal edge drains. These drains should be free of any sags or humps, as these will impede the flow of water through the system.

Once road construction is completed, proper mowing schedules should be practiced to ensure that vegetation will not impede the performance of the drainage systems. After mowing, grass clippings and other debris should be removed from the concrete headwalls or splash pads. Over time, debris can collect in front of the outlet and prevent water from exiting the system. This condition is shown in Figures 2.4 and 2.5, respectively.

Routine Inspection Survey

Routine visual inspection of edge drain systems is an important practice for improving the effectiveness of pavement subdrainage systems. Maintenance crews should be provided with inspection forms to record information about edgedrain systems. Recorded information includes date, location of system, system condition, pavement condition, and other site specific information important for maintenance purposes. Inspections should be included in any maintenance schedule where edgedrains are present. A sample inspection form is shown in Figure 2.6.

Figure 2.4 Outlet Clogged With Grass Clippings

Figure 2.5 Water Flowing From Cleared Outlet

COLLECTOR SYSTEM INSPECTION FORM

SITE INFORMATION

DISTRICT ____________ COUNTY ____________ HWY No. ____________ DIRECTION ____________

PROJECT No. ____________ CONTRACT No. ____________ CONTRACT LENGTH ____________ (MILES)

PROJECT LOCATION ________________________

DATE OF INSPECTION ____________ INSPECTED BY ____________

DRAIN No. ________ DRAIN LOCATION ________________________

DISTANCE FROM PREVIOUS DRAIN ____________ (IN FEET) ____________ (IN MILES)

OBSERVATIONAL INFORMATION

LOCATION OF COLLECTOR:	1. END OF PAVEMENT	2. END OF SHOULDER	3. INTERMEDIATE POINT
TYPE OF COLLECTOR SYSTEM:	[ ] UNDERDRAIN OR K-PIPE		[ ] FIN OR X-DRAIN
TYPE OF UNDERDRAIN PIPE: (CIRCLE ONE)	1. CORRUGATED STEEL 3. PLASTIC CORRUGATED	2. BITUMINOUS COATED CORRUGATED STEEL 4. CLAY	5. OTHER ________
TYPE OF OUTLET PIPE: (CIRCLE ONE)	1. CORRUGATED STEEL 3. PLASTIC PLAIN	2. BITUMINOUS COATED CORRUGATED STEEL 4. PVC CORRUGATED PLASTIC	5. OTHER ________
VERTICAL DEPTH OF OUTLET PIPE FROM PAVEMENT SURFACE ____________ (FEET)			
SIZE OF OUTLET PIPE:	6" DIA.	4" DIA.	OTHER ________
SLOPE OF OUTLET PIPE:	FORWARD	REVERSE	FLAT
CONDITION OF OUTLET OPENING:	FULL SIZE	PARTIAL	DAMAGED
SCREEN PRESENT:	YES	NO	TYPE ________
OUTLET MARKER PRESENT:	YES	NO	CONDITION ________
HEAD WALL PRESENT:	YES	NO	CONDITION ________
EROSION CONTROL APRON PRESENT:	YES	NO	TYPE ________
CONDITION OF VEGETATION ON EMBANKMENT:	MOWED	NOT MOWED	
MOVEMENT OF PROBE:	FREE	PARTIAL	BLOCKED
WATER PRESENT INSIDE DRAIN:	YES	NO	
IF YES:	FREE FLOWING	STANDING	

DISTANCE TRAVERSED BY PROBE ____________ (FEET)

CAMERA OBSERVATIONS: ________________________

____

____

ADDITIONAL OBSERVATIONS: ________________________

Figure 2.6 Sample Inspection Form (12)

Video Inspection

To assure construction damage has not occurred, a video imagescope should be used to inspect the collector pipe and outlet pipe system. As part of FHWA Demonstration Project no. 87, Daleiden et al. (13) used a closed circuit video monitoring system to inspect drainage systems in 27 states. Problems observed in the study included silted-in systems, crushed segments, rodents' nests, humps, and sags. Crushing of pipes was observed on highways not yet opened to traffic, as frequently as on in service highways. This demonstrated the need for video inspection as a quality assurance/quality control measure.

Employees from the engineering firm conducting the surveys, Fugro-BRE, suggested that video inspection equipment be mounted onto a utility vehicle (14). The request was granted, allowing technicians to drive to an outlet and feed the camera off the back end of the utility vehicle. The utility vehicle and video inspection equipment can be seen in Figure 2.7.

Figure 2.7 Video Inspection Vehicle (14)

Joint Sealing

Preventative maintenance procedures can also increase the effectiveness of subdrainage systems. The most significant preventative maintenance practice is edge joint sealing. Longitudinal edge joints allow direct infiltration of water into the pavement. This infiltration jeopardizes the integrity of both the pavement and shoulder. A study by the Minnesota Department of Transportation evaluated a control section with unsealed edge joints versus a test section where edge joints were sealed (15). Resulting outflow volumes of three rainfall events over each section are provided in Table 2.4. It was concluded that sealing edge joints could reduce infiltration of water into pavement sections by hundreds to thousands of liters. Benefits due to joint sealing can be seen in Figure 2.8.

Table 2.4 Minnesota Edge Joint Sealing Results

Event	**Control Volume Drained (liters)**	**Test Volume Drained (liters)**	**Reduction Between Sections (%)**
1	2607	281	89
2	1434	73	95
3	2831	482	83

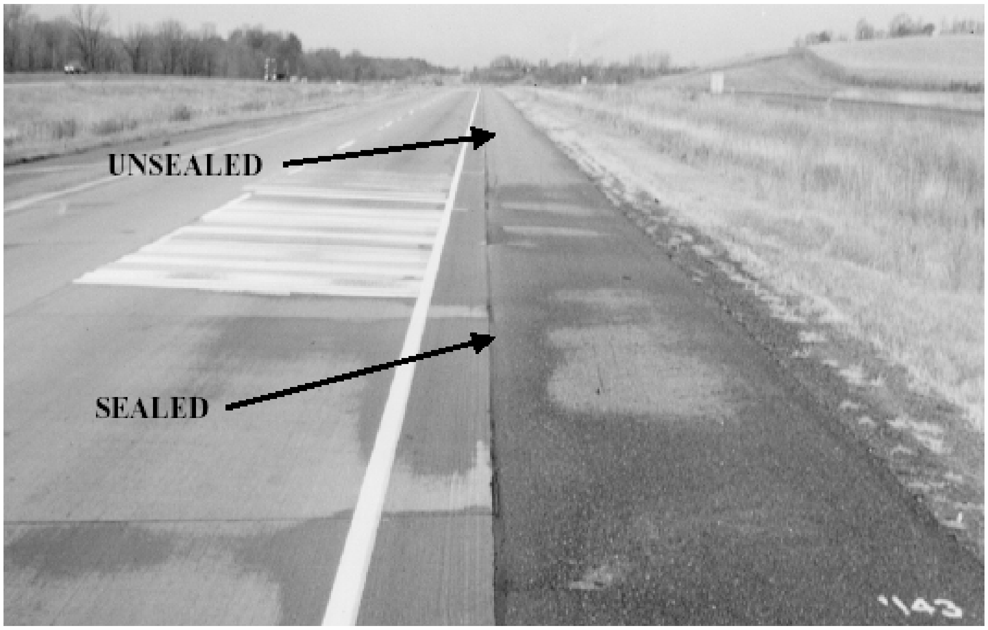

Figure 2.8 Effect of Sealing Edge Joint (15)

MDOT Specifications

A review was conducted of MDOT's standards and specifications concerning internal drainage systems. The following paragraphs are a summary containing the salient points from MDOT Special Provision No. 907-306-1 and Section 605 of MDOT's standards and specifications.

Special Provision No. 907-306-1

MDOT's specification (16) for OGDL consists of an asphalt treated drainage course. Asphalt drainage course is a bituminous drainage layer consisting of crushed aggregate and asphalt cement. The aggregate used should be crushed limestone, sandstone, granite, gravel, or reclaimed concrete pavement.

The most common aggregate used is a no. 57 crushed limestone; however, if a gravel or blended mixture is used, the requirements of Table 2.5 should be met.

Table 2.5 Requirements for Gravel or Blended Mixtures (16)

Design Master Range	
Sieve Size	% Passing
1”	100
¾”	90-100
½”	89 max
No. 4	20 max
No. 8	15 max
No. 200	3.5 max

The bituminous material used in the mixture is petroleum asphalt cement, Grade PG 67-22. For a non-gravel mixture, asphalt cement content will be 2.5 percent by weight of total dry aggregate ± 0.4 percent. The temperature of the completed mix should be 235° ± 15° F. For gravel and/or blended mixtures, asphalt cement content will be 2 to 3 percent by weight of total mixture, as determined by mix design, with a tolerance of ± 0.4 percent. The temperature of this mix should be 275° ± 25° F. Both the gravel and non-gravel mixtures should contain 1% hydrated lime.

Asphalt drainage course mix temperature is lower than that of other asphalt mixes. A lower temperature is specified to prevent drain-down of the asphalt cement during hauling and placing (17). If excessive drain-down were to occur during transport of asphalt drainage course, the mixture could stick to the truck bed. Drain-down could also interfere with the effectiveness of asphalt paving equipment.

Sampling and testing of the asphalt drainage course should be conducted one time for every 1000 tons of drainage course produced. The non-gravel mixtures should have tests on their gradation and asphalt cement content performed on samples obtained from the plant. Gravel and blended mixtures should have tests on their gradations, asphalt cement, and voids on samples obtained at the plant. Gravel and blended mixtures should comply with the job mix formula control limits shown in Table 2.6:

Table 2.6 Job Mix Control Limits (16)

Job Mix Formula Control Limits	
Sieve, % Passing	Tolerance, %
½" and larger	±6
No. 4	±5
No. 8	±5
No. 200	-2 to +1
AC	±0.4
Calculated Voids	20% min

Asphalt drainage course, unless otherwise noted, should be spread and compacted in one layer to a 4-inch thickness. Asphalt drainage course cannot be placed on a wet or frozen surface, or when the surface or air temperature is less than 40° F.

Section 605 - Underdrains

MDOT specifications (18) state that longitudinal edge drain trenches should be excavated to the dimensions and grade shown on the plans. If trench dimensions are not shown on the plans, the trench shall be at least as wide as the outside diameter of the pipe plus eight inches on each side, and shall be deep enough to allow proper installation of the pipe and covering. The vertical tolerance for the trench shall be ± ½ inch. The horizontal tolerance shall be +1 inch.

Fabric used to line the trench shall be Type V geotextile fabric. The geotextile shall be stretched, aligned, and placed in a wrinkle free manner. Adjacent rolls of fabric shall be overlapped from 12 to 18 inches with the preceding roll overlapping the following roll in the direction the material is being spread. The untreated permeable material used to backfill the trenches shall be Type 57 filter material. Filter material shall be placed into the trench immediately after the pipe has been laid. Should the fabric be damaged, the damaged section shall be either completely replaced or shall be appropriately repaired.

Pipe for the longitudinal edge drains and edge drain outlets shall be of 4-inch nominal size. The pipe shall be either corrugated high density polyethylene (HDPE) conforming to AASHTO designation M 252, or a Schedule 40 or Schedule 80 polyvinyl chloride (PVC) pipe conforming to ASTM designation D 1785. When corrugated HDPE is used, joints shall be made with split couplings, corrugated to engage the pipe corrugations, and shall engage a minimum of four corrugations. PVC pipe and fittings shall be joined with commercial quality solvent cement and primer specifically manufactured for use with rigid PVC plastic pipe and fittings.

A video inspection of the edge drain shall be conducted by the contractor upon completion of a roadway section. A video record and a written report for each line inspected shall be provided to the Engineer. A minimum of 50% of the entire edge drain system for a project shall be video inspected. Video equipment used for inspection shall meet the following minimum requirements (18):

1. Providing color video inspection of pipelines for 4 inch inside diameter pipe in a wet, corrosive environment and negotiating a 90° bend in a smooth bore of corrugated pipe. The color camera must have a minimum 400-line horizontal resolution.

2. Video inspecting of up to 300 linear feet of pipe by pushing, pull cabling, jetting, or tractoring the camera through the line and recording the condition on tape.

3. Equipped with a video monitor capable of allowing live viewing of the video inspection.

4. Displaying and recording on tape, the date, line identification, footage, and type of pipe deficiency.

5. Recording the distance traversed by the camera to within 0.5 feet, allowing for overlapping of distances if a reversal is required to permit full inspection.

A written report of the drain inspection shall be completed on the MDOT Edge Drain and Edge Drain Outlet/Vent Inspection Form. Any foreign materials restricting movement of inspection equipment shall be flushed from the system.

Design plans for MDOT edge drain systems consist of longitudinal edge drains with outlets spaced every 200 feet. At 800 foot intervals there is a double outlet. One barrel acts as a drain and the other barrel acts as a vent for the next 800 feet of longitudinal edge drain. A typical MDOT edge drain system is shown in Figure 2.9.

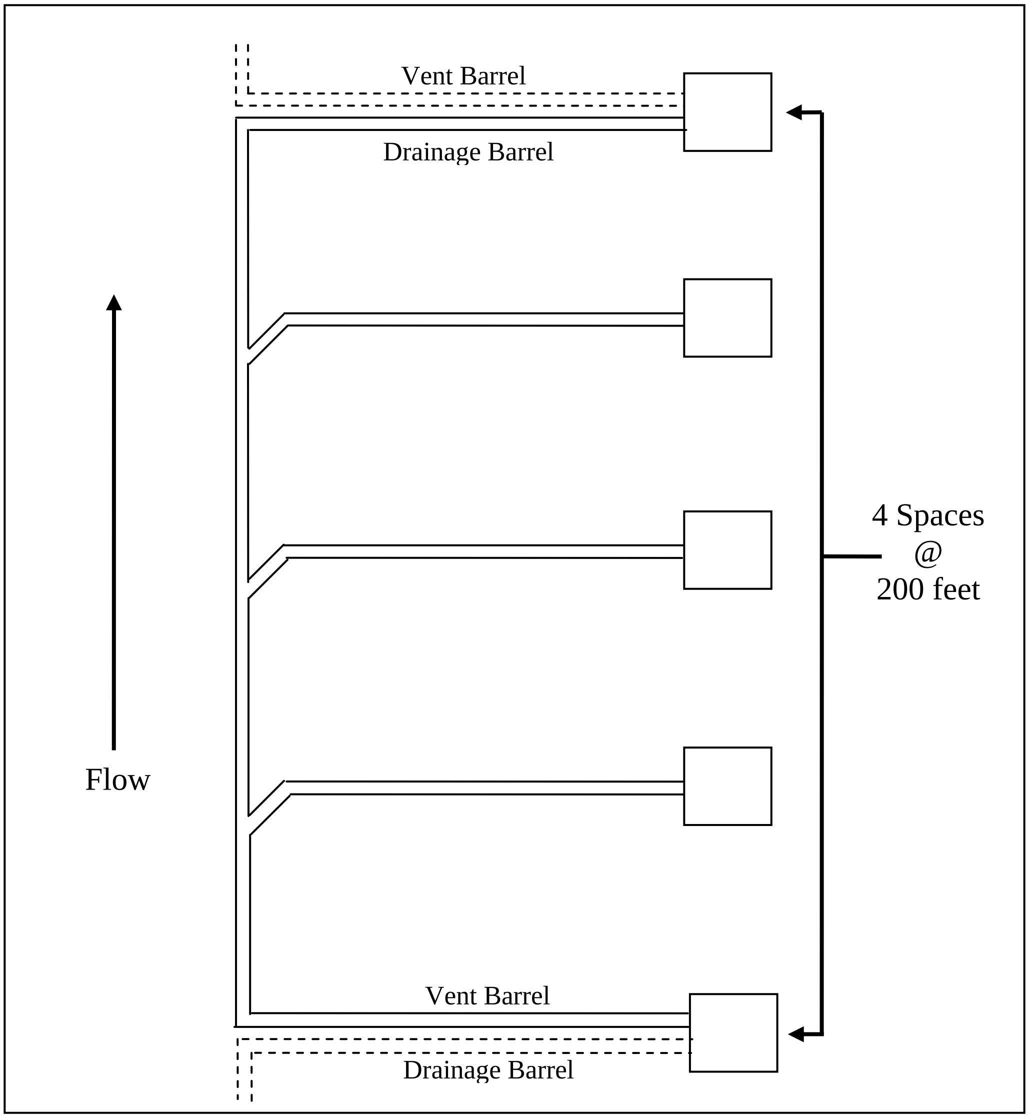

Figure 2.9 MDOT Edge Drain System

Pavement Distress Surveys

Pavement distress surveys can provide valuable information when conducting pavement drainage studies. One widely adopted practice is the Pavement Condition Index (PCI) method for roads and parking lots as developed by the U.S. Army Corps of Engineers (19). The following sections contain a brief overview of this method of determining PCI.

Sample Units

Pavement sections to be surveyed should be broken into sample units. A pavement sample unit should be 20 slabs (± 8 slabs if not evenly divisible by 20) for a Portland Cement Concrete (PCC) pavement, and 2500 square feet (± 1000 square feet if not evenly divisible by 2500) for an Asphalt Concrete (AC) pavement.

Data Collection

Visual inspection of the pavement is used to identify the type of distresses present. There are nineteen different distress types for both flexible and rigid pavements. Each distress can have a severity level of low (L), medium (M), or high (H). Distresses are measured and their severity is recorded on data collection forms. Data collection forms are also used to record the location, date, section, sample unit size, slab number, name of surveyor, and sketch of the section.

PCI

Calculation of the PCI begins by adding up the total quantity of each distress type at each severity level and recording the data under the total severities section of the data collection form. Each total quantity is divided by the total area of the sample unit and multiplied by 100 to obtain a percent density of each distress type and severity. Percent density values and level of severity are used to generate deduct points from deduct value curves. Using the deduct value method; pavements are ranked on a 100 point index. A score of 100 represents a perfect pavement and pavements are further rated as follows:

- 85 to 100 – Excellent
- 70 to 85 – Very Good
- 55 to 70 – Good
- 40 to 55 – Fair
- 25 to 40 – Poor
- 10 to 25 – Very Poor
- 0 to 10 – Failed

The described method works under the philosophy that a pavement containing two distresses each having a deduct value of 35 is not as severe as a pavement containing one distress with a deduct value of 70. However, a series of curves were developed to correct the total deduct value using the total number of distresses with a deduct value greater than 5 and the total deduct value. The corrected deduct value is subtracted from 100 to define the PCI.

CHAPTER III

RESEARCH TEST PLAN AND INSTRUMENTATION

This chapter describes the field study test plan, procedure, and instrumentation. Primary study objectives were to evaluate the performance of MDOT's existing subdrainage systems and to review current maintenance practices.

Field Study

Work for the field study was conducted on US Hwy 82 pavement sections located in Oktibbeha County. Both concrete and asphalt pavements were visited to select specific sections for evaluation. Selections were made by finding tangent sections containing one continuous edge drain system. A visual observation was made of the embankment slopes alongside the selected sections to ensure that there was adequate room for installation of all equipment.

The selected concrete test section is constructed with 11-inches of jointed concrete pavement, 4-inches of asphalt drainage course, 6-inches of cement treated granular material, and 10-inches of lime treated subgrade.

The asphalt test section is constructed with 9.5-inches of hot mix asphalt, 4-inches of asphalt drainage course, 6-inches of cement treated granular base, and 10-inches of lime treated subgrade.

After site selection, three point profiles were collected on the inside edge, outside edge, and centerline of each test section by an MDOT survey party. These profiles provided information about the longitudinal and cross slopes of the sections to be evaluated, as well as helping show any discontinuities not visible to the naked eye. A distance measuring wheel was used to obtain the distance between outlets to the nearest foot.

Once the sites were selected and all survey data collected, instrumentation was installed to collect data needed to calculate the pavement drainage system efficiency.

Instrumentation Overview

The following is an overview of the equipment used to evaluate the performance of selected drainage systems. Five sets of equipment were obtained and/or constructed for this study. Four sets of equipment were in use at all times for collection of data over an entire 800 foot drainage system. A fifth piece of equipment was also available for replacement in case of equipment failure in the field.

Data Collection and Storage

Data collection and storage was accomplished using a Campbell Scientific CR 1000 Measurement and Control System. The CR 1000 is powered by an external 12V battery power source. In this study power was supplied using a deep cycle/trolling marine battery. The batteries were in service for over a year and never required recharging.

Creating a program for data retrieval and storage can be done using Short Cut for Windows software (20). Short Cut is a Windows based program for setting up a data collection and storage program. Short Cut helps to generate a program using four steps:

1. Create new program
2. Select sensors
3. Select outputs
4. Finish/Compile program

Short Cut will also generate a wiring diagram to assist with connections of all instrumentation.

After a program is written a connection must be made between the computer and the CR 1000. This is accomplished by connecting a 9-pin serial cable between the RS-232 port on the CR 1000 and the serial port on the computer. A USB serial adaptor was required for connection to the computer used in this study.

Once the serial cable is connected, PC200W software can be used to setup the datalogger, synchronize the clock, select and send programs, monitor values, collect data, and view data (20).

The select and send tab allows for programs that were generated using the Short Cut program to be loaded onto the CR 1000 datalogger.

The monitor values tab will display measurements currently being made, as long as the datalogger is connected to the computer. This allows the user to verify that the selected programs and instrumentation are working properly.

The collect data tab allows for collection of all data from the datalogger, or allows for collection of new data from the datalogger in the case where previous data has already been retrieved.

The view data tab will open downloaded files and display data in columns. This tab also has graphic capabilities, but due to the limitations of the software, data for this study was loaded into Excel and graphed. A CR 1000 Measurement and Control System is shown in Figure 3.1.

Figure 3.1 CR 1000

Rain Gauge

Rainfall events were recorded with a Texas Electronics Model TR-525USW tipping bucket rain gauge as shown in Figure 3.2. The rain gauge consists of a collector funnel, eight inches in diameter, which directs the water to a tipping bucket mechanism. A magnet attached to the tipping bucket actuates a magnetic switch causing a switch closure with each tip of the bucket. The rain gauge was factory calibrated so that each tip of the bucket accounts for 0.01 inches of rainfall with an accuracy of 1% for 1-inch of rainfall per hour or less (21).

Figure 3.2 Rain Gauge

Outflow Bucket

A device was fabricated in the Mississippi State University Department of Civil and Environmental Engineering shop facility to collect and measure outflow from the highway edge drains. Drawings and material specifications for a dual chambered tipping bucket were obtained from the U.S. Army Corps of Engineers Research and Development Center. The design originated with the Wisconsin Department of Transportation. Modifications were made to the original design and materials for the bucket. Ahmed et al. (9) suggested that rubber pads be installed at the base of the bucket to absorb impact when the chambers tilt. This modification was incorporated in the construction of buckets for this project. After initial bucket installation, water was observed freely running from the collector. Further observation revealed that water which was intended to drip into the tipping mechanism was running across the bottom of the collector portion of the bucket and down the sides of the housing. The problem was addressed by attaching flanges to the hole cut into the top collector portion of the bucket. Adding flanges created a funnel to properly divert water into the tipping mechanism.

Each tipping mechanism was individually lab calibrated by gradually adding water to a chamber causing a tip to occur. Measured volumes for each tip were recorded and their average was programmed into the datalogger. Figure 3.3 shows a fully assembled outflow meter. Drawings, modifications, and calibration information can be found in Appendix A.

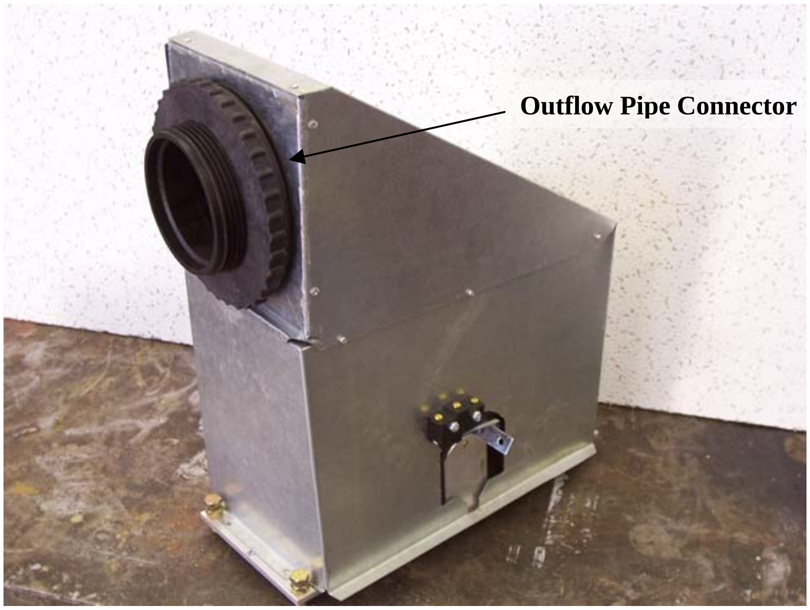

Figure 3.3   Outflow Bucket

Equipment Enclosures

Enclosures were needed to protect the instrumentation from weather and tampering. To accomplish this, wooden boxes were constructed using ¾" pressure treated plywood. Once constructed, the boxes were primed, painted, and caulked to protect from environmental damage. Locks and "High Voltage" signs were added to help reduce or prevent tampering while the equipment was in the field. Concrete pads were poured on the road embankment by MDOT maintenance personnel to provide a stable and level surface to mount the enclosures. A hammer drill was used to drill holes in the concrete pads and the enclosures were secured to the pads with concrete anchor bolts. Figure 3.4 shows an equipment enclosure mounted to a concrete pad.

Figure 3.4   Equipment Enclosure

Precipitation vs. Outflow

After installation and calibration of all instrumentation, collection of data began in an effort to identify the percentage of water removed from the pavement sections. Percentage of water removed from the pavement drainage system is found by evaluating the precipitation versus outflow of a pavement section.

Total precipitation volume is found by multiplying the total rainfall by the surface area. Rainfall is recorded to the nearest hundredth of an inch by the rain gauge. The surface area comes from the length as measured between outlets and the width from the centerline of the pavement to the outside edge of the drainage trench. The calculation for total precipitation volume is shown in Equation 3.1.

$$I * A = TPV \qquad \text{Equation (3.1)}$$

Where:

I = Inches of Rainfall

A = Surface Area

TPV = Total Precipitation Volume

Total outflow volume is measured by recording the total number of tips from the outflow tipping buckets. Each tipping bucket has a known volume per tip. These volumes are provided in Appendix A. With the total number of tips recorded, total outflow volume is calculated by Equation 3.2.

$$N * V = TOV \qquad \text{Equation (3.2)}$$

Where:

N = Number of Tips

V = Volume per Tip

TOV = Total Outflow Volume

Using total precipitation volume and total outflow volume, percentage of water removed from the drainage system can be calculated by Equation 3.3.

$$\left(\frac{TOV}{TPV}\right)*100 = \%removed \qquad \text{Equation (3.3)}$$

Where:

TOV = Total Outflow Volume

TPV = Total Precipitation Volume

Distress Survey

Condition of the pavement test sections was quantified in terms of pavement distress. The approach was to utilize the terminology and format provided by ASTM D 6433-99 (Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys) (22).

Actual distresses were quantified using video images of the pavement sections collected using MDOT's "Automated Road and Pavement Condition Surveys" van as built by Pathway Services, Inc. The van is shown in Figure 3.5. Collecting images took minutes and did not require traffic control since no people were required to be in the road.

Figure 3.5   MDOT Profiler Van

Once images were collected, they were brought into the office and analyzed using Path View II software from Pathway Services, Inc. Collected images were displayed on the computer screen and tools within the software were used to map and measure each distress. These measured distresses were used to perform the PCI calculations as described in ASTM D 6433-99.

Maintenance Survey

In an effort to find out more information about maintenance of pavement drainage systems, a survey was developed and sent out to other transportation agencies. Questions in the survey were as follows:

1. Does your agency currently construct internal pavement drainage systems?

2. If yes, briefly describe your design.
3. Do you have a maintenance plan for your pavement drainage systems, most specifically edgedrains?
4. If yes, please explain your maintenance plan, including schedule.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter provides results obtained from execution of the test plan. Discussion will begin with the data collected on the asphalt test section. The next step will be a look at the data collected from the concrete test section. Lastly will be a summary of the responses gained from the maintenance survey questionnaire.

For this study, four significant rainfall events were obtained for both the asphalt and concrete test sections. Originally, this study intended to look at several more rainfall events and possibly other test sections. Unfortunately, data was only able to be collected on the Oktibbeha County test sections due to drought conditions throughout the duration of the project. On September 19, 2007, the rainfall deficit was 18.71 inches below normal for Columbus, Mississippi (23). Columbus is located approximately 25 miles from the test sections in this study.

Asphalt Test Section

The following is a review of the data collected on the asphalt pavement test section. A summary of the results for the asphalt test section is provided in. Table 4.1 with a more in-depth discussion following. A graphical representation of each rainfall event is provided. It should be noted that the vertical scale changes for each rainfall event in an effort to show detailed trends for each event.

Table 4.1 Summary of Asphalt Test Section Results

Asphalt Test Section					
PCI Rating: 93.1 "Excellent"					
Event	Rainfall (cft)	Outflow (cft)	Water Removed (%)	Time to Drain (hours)	AASHTO Rating
31-Jan	975.4	438.8	44.9	20	Good
1-Apr	276.6	64.3	23.2	23	Good
10-Apr	640.6	161.1	25.1	23	Good
14-Apr	567.8	123.6	21.8	22	Good

Asphalt Section Profile

Survey rod readings for the outside pavement edge are listed in Table 4.2. These readings show elevation changes along the flow path of the water in the collector trench.

Table 4.2 Asphalt Profile

Station	Rod Reading
1+00	3.15
1+25	3.23
1+50	3.29
1+75	3.34
2+00	3.36
2+25	3.41
2+50	3.44
2+75	3.47
3+00	3.50
3+25	3.48
3+50	3.46
3+75	3.48
4+00	3.47
4+25	3.47
4+50	3.46
4+75	3.47
5+00	3.48
5+25	3.49
5+50	3.51
5+75	3.55
6+00	3.57
6+25	3.59
6+50	3.60
6+75	3.61
7+00	3.64
7+25	3.67
7+50	3.65
7+75	3.65
8+00	3.65
8+25	3.67
8+50	3.65
8+75	3.65
9+00	3.71
9+25	3.74
9+50	3.72
9+75	3.74
10+00	3.74
10+25	3.73
10+50	3.76
10+75	3.77
11+00	3.76
11+25	3.73
11+50	3.65
11+75	3.67
11+92	3.70

Distance measurements between the outlets showed that the drainage system was not built exactly to specification. Recall that MDOT specifications dictate there should be four outlets spaced at 200 feet. For this section, however, spacing measured between outlets is as follows:

- 275’
- 270’
- 267’
- 280’

These measurements will be used when calculating the area of infiltration.

Asphalt Pavement Condition Survey

Low severity longitudinal and transverse cracking was observed on the asphalt section. The PCI for the section was calculated as 93.1. That value gives the asphalt test section a distress rating of “excellent”. Asphalt test section distress survey sheets are provided in Appendix B.

January 31, 2007, Rainfall Event

Rainfall totaling 0.67” fell on the asphalt test section over a 31-hour period. The rain event began at approximately 8:00 P.M. on January 30th and the first outflow was recorded at approximately 11:20 P.M. on January 30th.

Converting 0.67” of rainfall into feet and multiplying by the area of infiltration (1092’ x 16’), gives a total precipitation volume of 975.4 ft^3. Outflow meters along the test section measured a total outflow volume of 438.8 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 44.9%.

The last recorded rainfall for this event occurred at approximately 2:55 A.M. on February 1st and the last outflow was recorded at approximately 11:00 P.M. on February 1st. The time to drain was less than one day and would classify as “Good” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.1 through Figure 4.4, respectively. Figure 4.5 is a plot of the January 31st rainfall event over the entire asphalt test section.

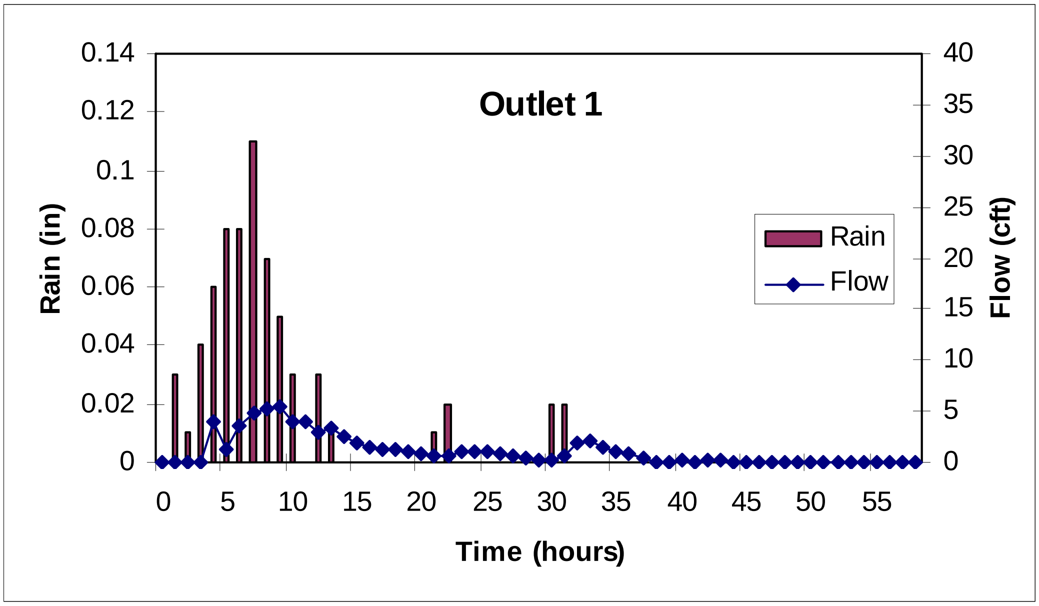

Figure 4.1 First Outlet Data January 31st Event

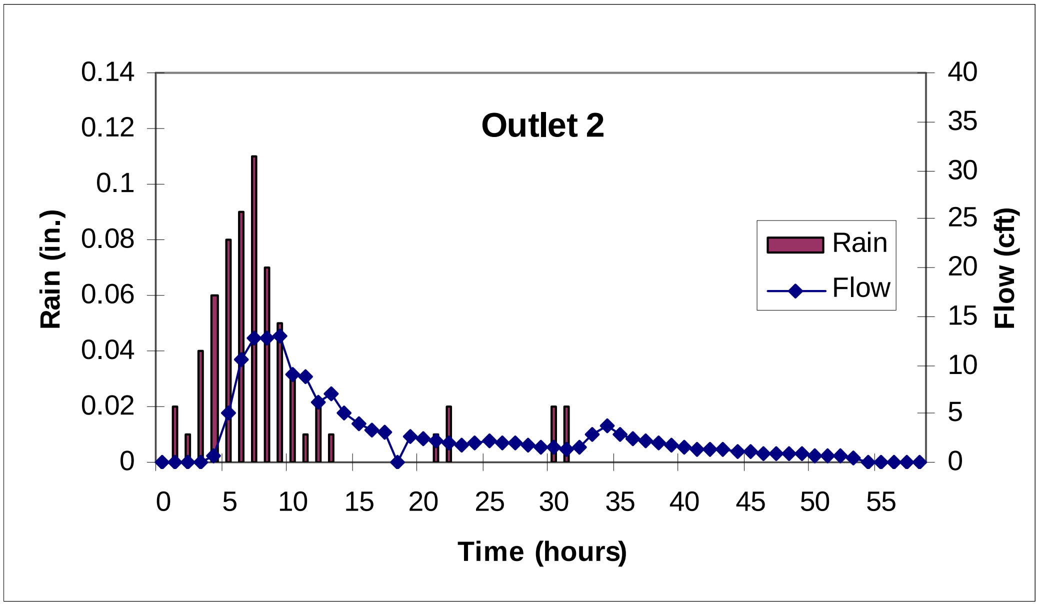

Figure 4.2 Second Outlet Data January 31st Event

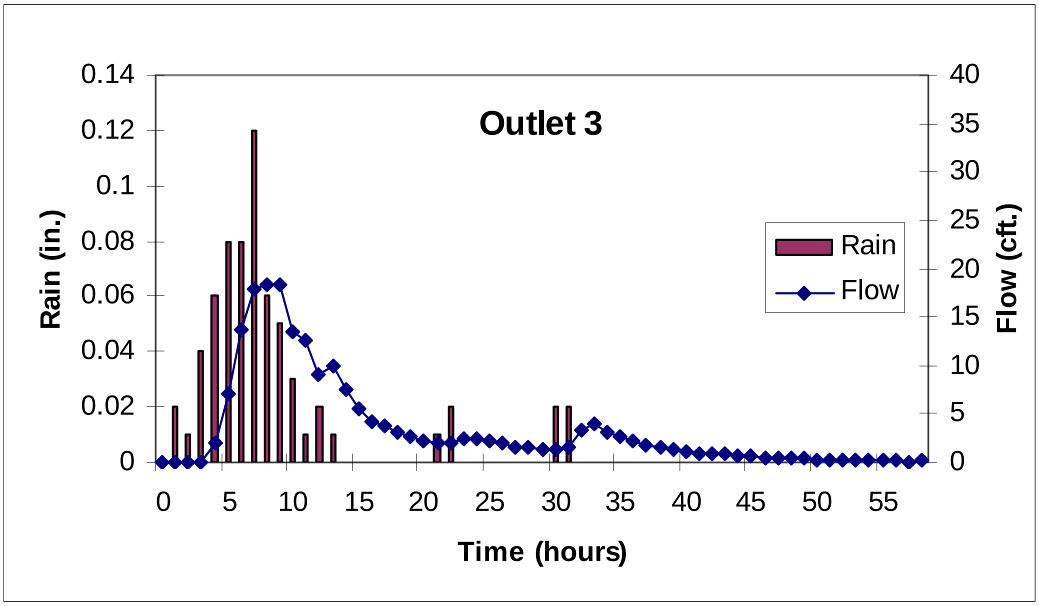

Figure 4.3 Third Outlet Data January 31st Event

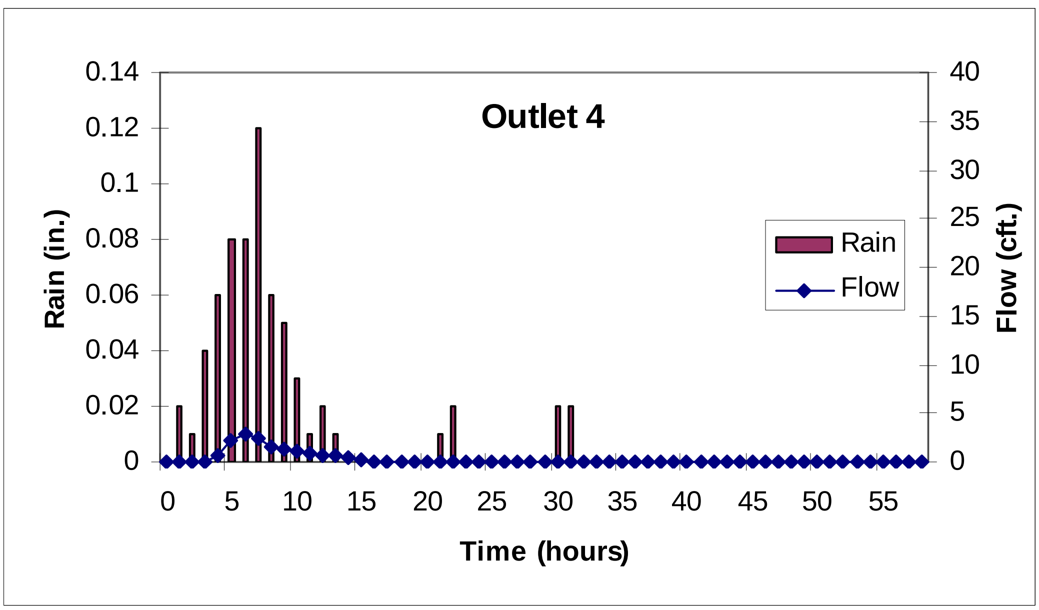

Figure 4.4 Fourth Outlet Data January 31st Event

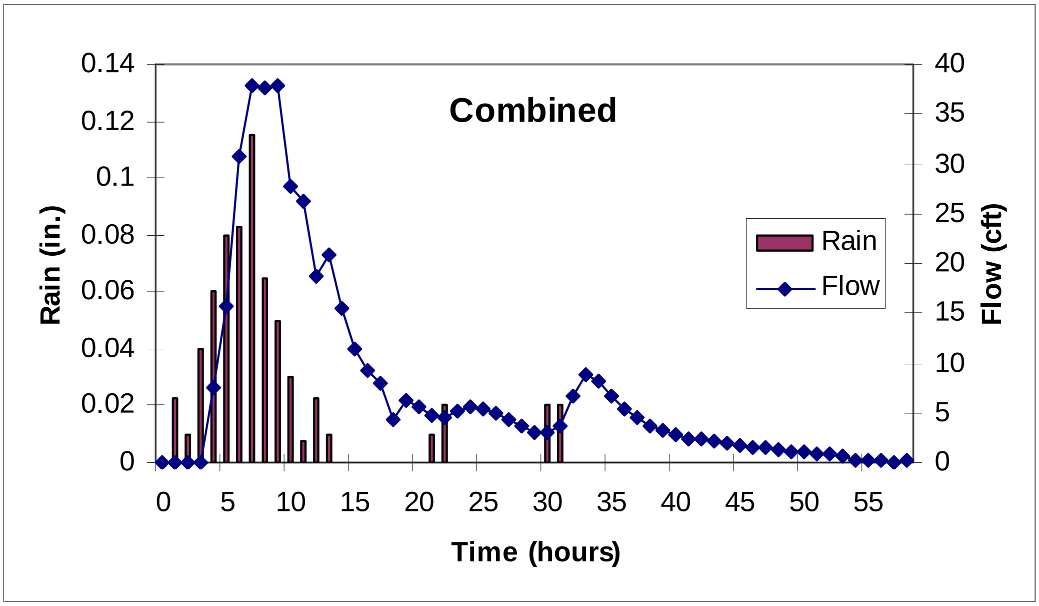

Figure 4.5 Combined January 31st Event for Asphalt Test Section

April 1, 2007, Rainfall Event

Rainfall totaling 0.19” fell on the asphalt test section over a 4-hour period. The rain event began at approximately 5:45 A.M. on April 1st and the first outflow was recorded at approximately 9:50 A.M. on April 1st.

Converting 0.19” of rainfall into feet and multiplying by the area of infiltration (1092’ x 16’), gives a total precipitation volume of 276.6 ft^3. Outflow meters along the test section measured a total outflow volume of 64.3 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 23.2%.

The last recorded rainfall for this event occurred at approximately 9:45 A.M. on April 1st and the last outflow was recorded at approximately 8:40 A.M. on April 2nd. The time to drain was less than one day and would classify as “Good” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the April 1st rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.6 through Figure 4.9, respectively. Figure 4.10 is a plot of the April 1st rainfall event over the entire asphalt test section.

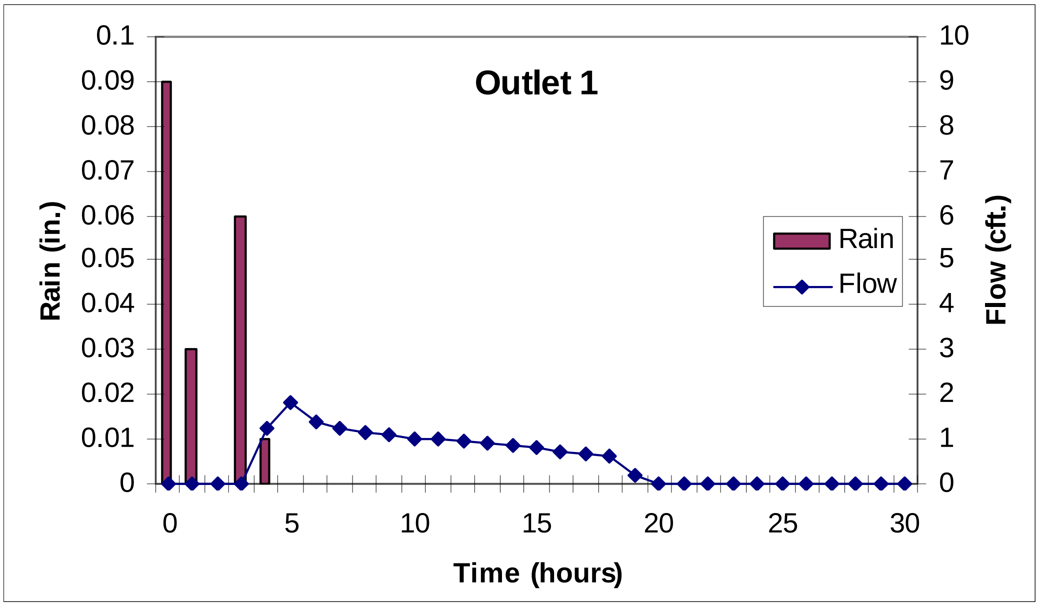

Figure 4.6 First Outlet Data April 1st Event

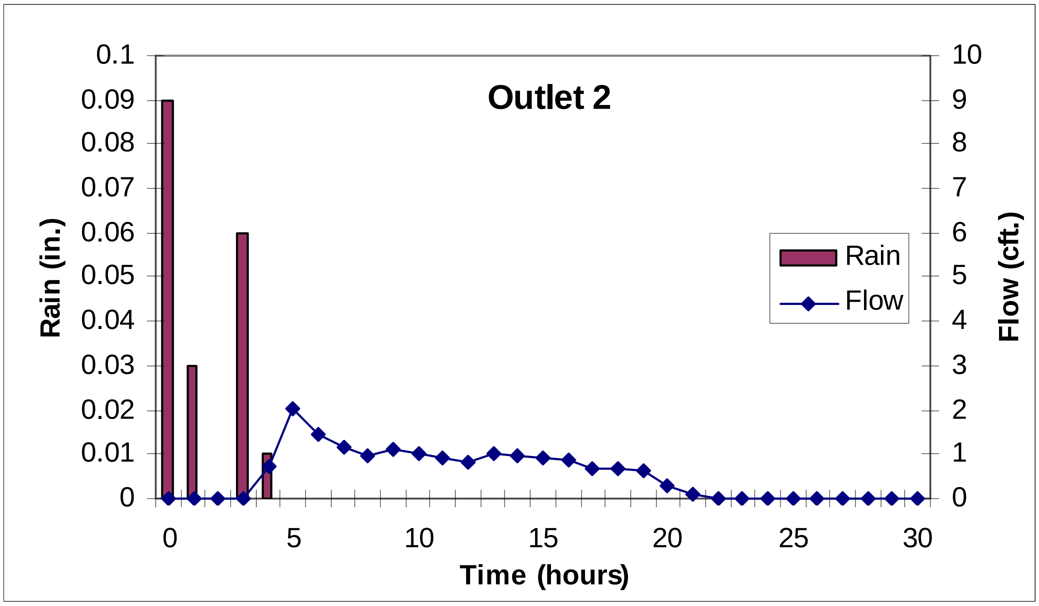

Figure 4.7 Second Outlet Data April 1st Event

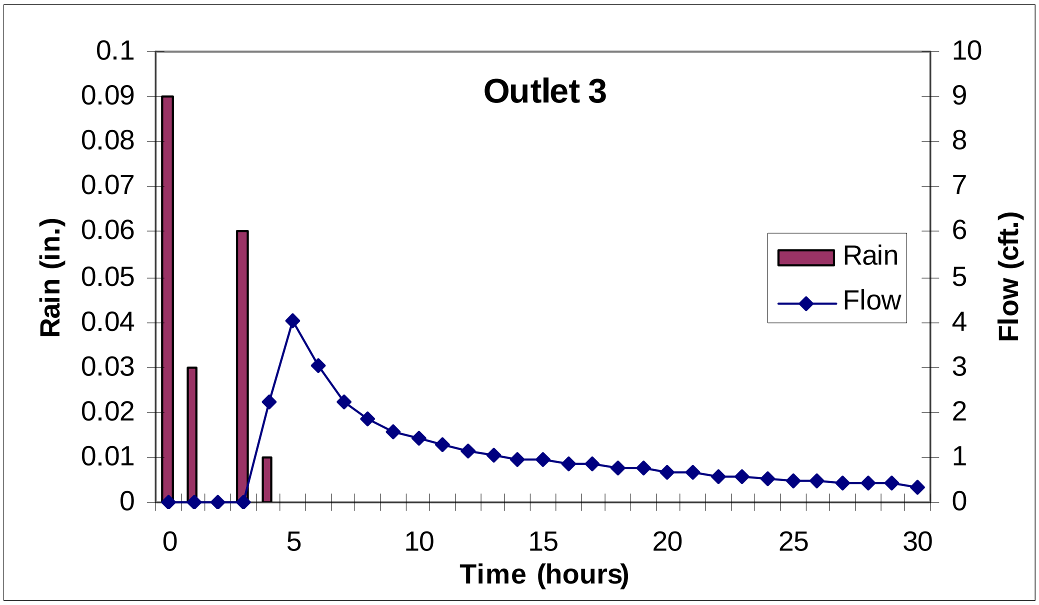

Figure 4.8 Third Outlet Data April 1st Event

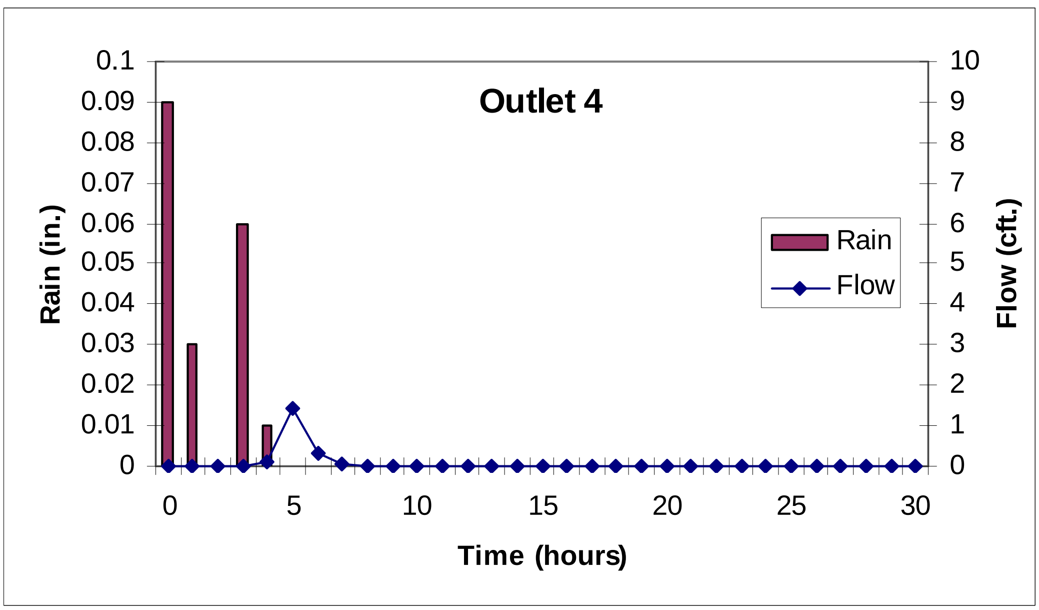

Figure 4.9 Fourth Outlet Data April 1st Event

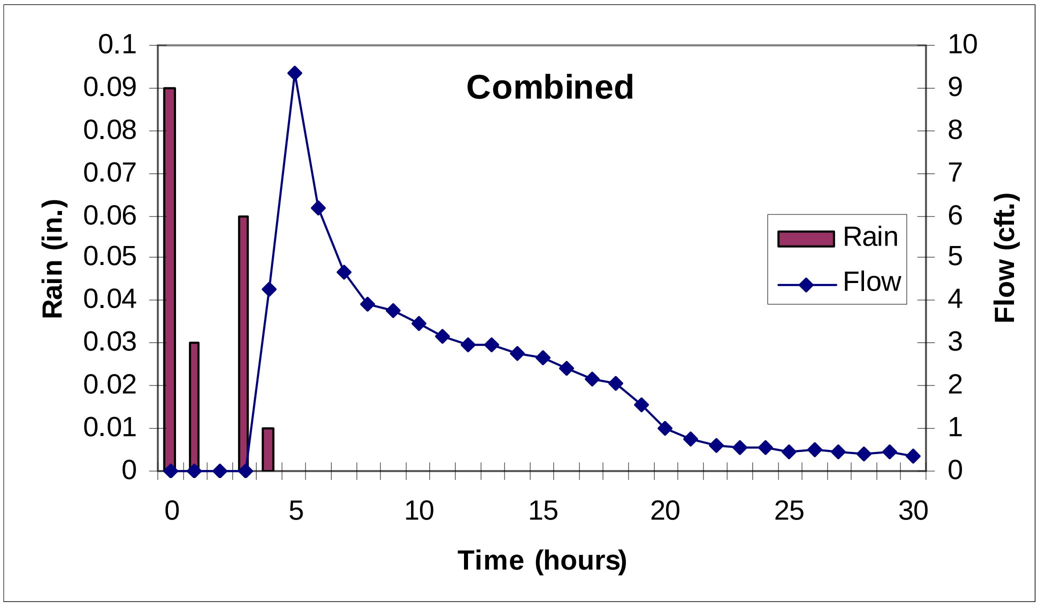

Figure 4.10 Combined April 1st Event for Asphalt Test Section

April 10 and 11, 2007, Rainfall Event

Two rainfall events totaling 0.44” fell on the asphalt test section within a 19-hour period. The rain event began at approximately 2:20 P.M. on April 10th and the first outflow was recorded at approximately 3:20 P.M. on April 10th.

Converting 0.44” of rainfall into feet and multiplying by the area of infiltration (1092’ x 16’), gives a total precipitation volume of 640.6 ft^3. Outflow meters along the test section measured a total outflow volume of 161.1 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 25.1%.

The last recorded rainfall for this event occurred at approximately 9:00 A.M. on April 11th and the last outflow was recorded at approximately 8:10 A.M. on April 12th. The time to drain was less than one day and would classify as “Good” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the April 10th and 11th rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.11 through Figure 4.14, respectively. Figure 4.15 is a plot of the April 1st rainfall event over the entire asphalt test section.

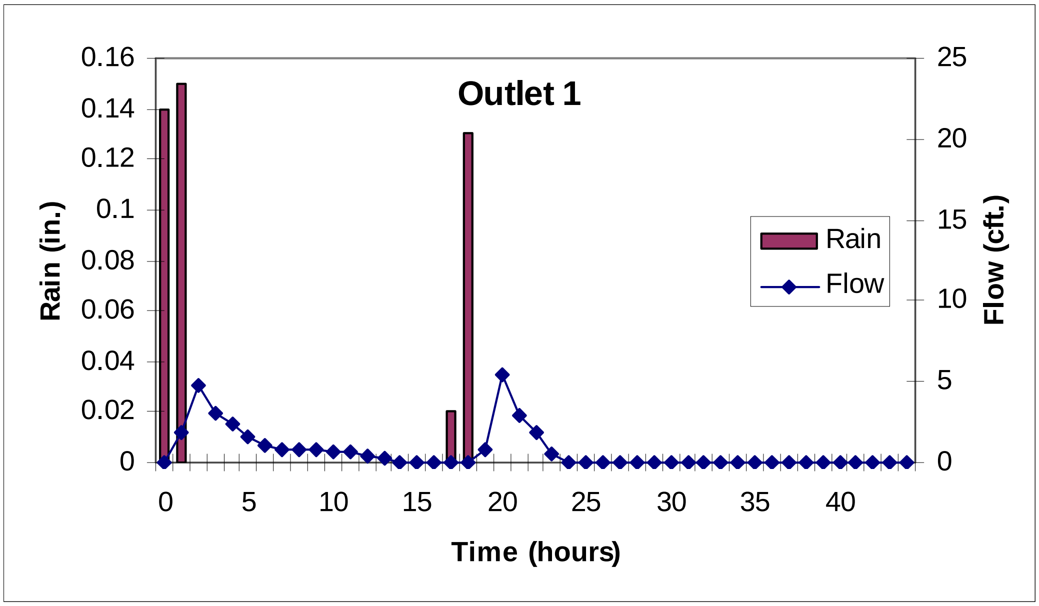

Figure 4.11 First Outlet Data April 10th and 11th Event

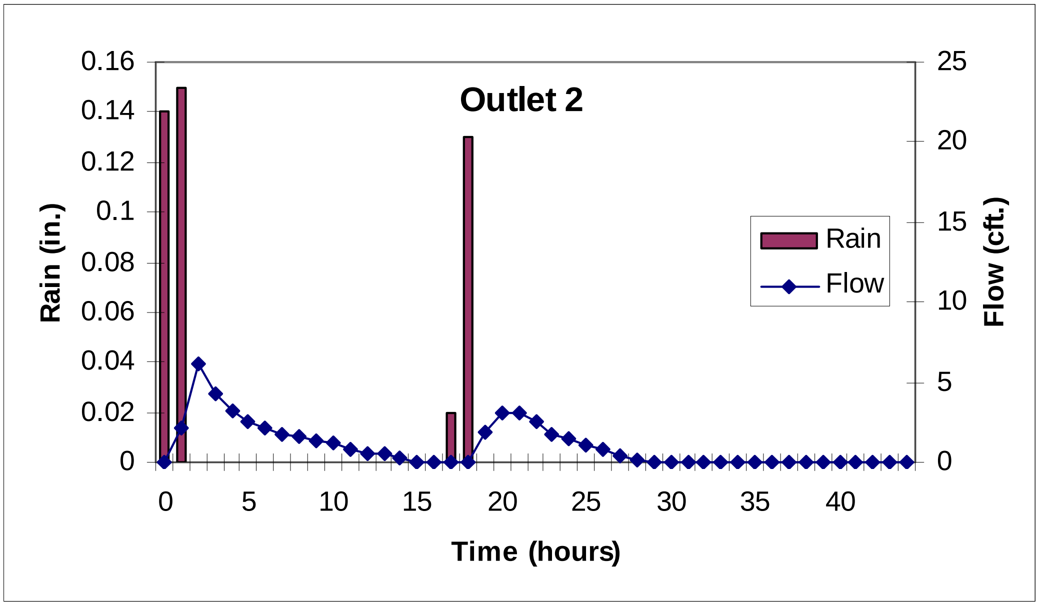

Figure 4.12 Second Outlet Data April 10th and 11th Event

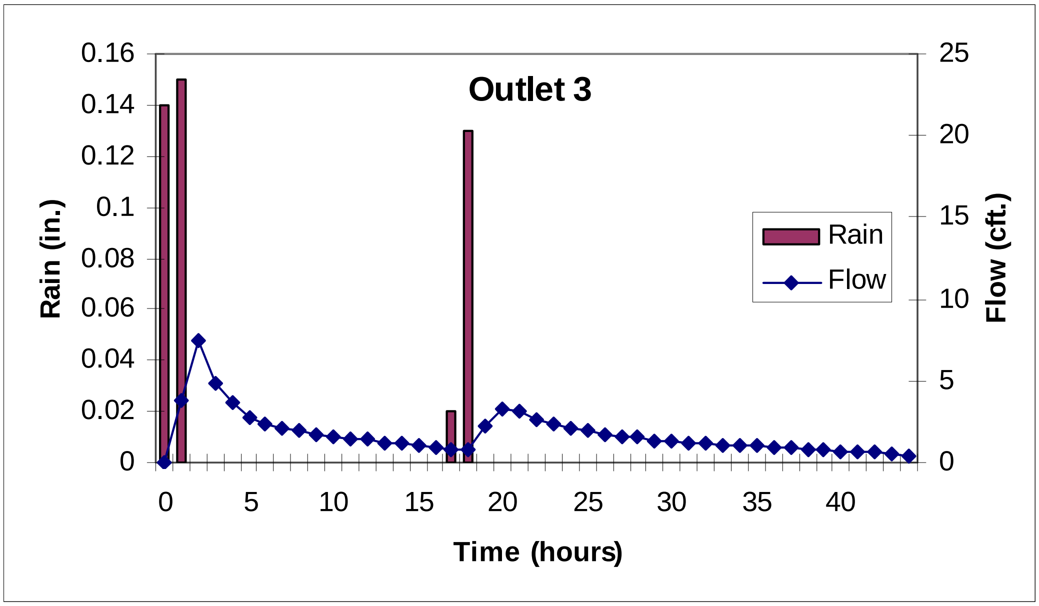

Figure 4.13 Third Outlet Data April 10th and 11th Event

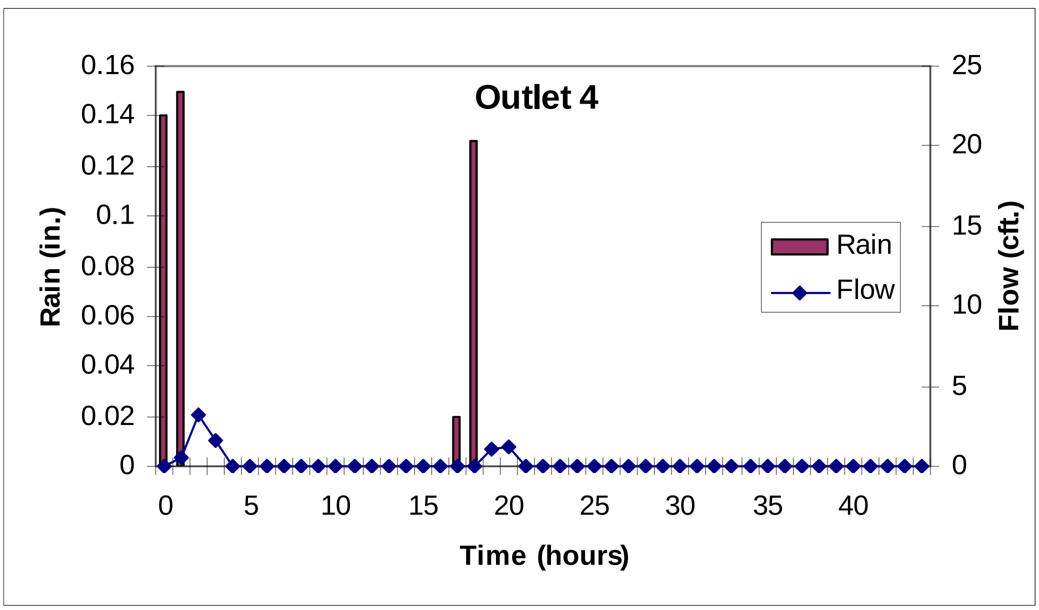

Figure 4.14 Fourth Outlet Data April 10th and 11th Event

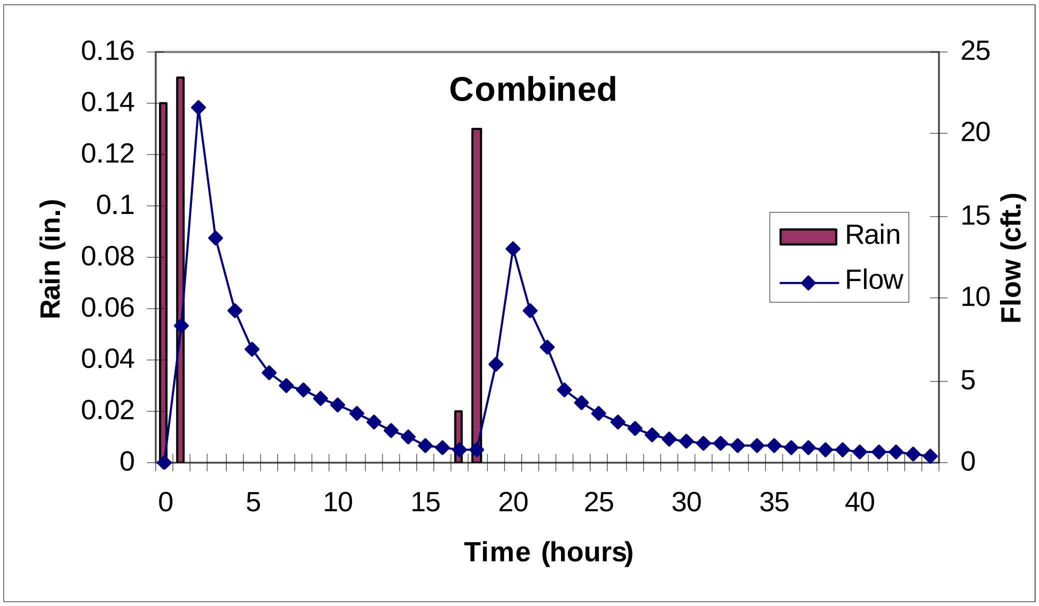

Figure 4.15 Combined April 10th and 11th Event for Asphalt Test Section

April 14, 2007, Rainfall Event

Rainfall totaling 0.39" fell on the asphalt test section over a 7-hour period. The rain event began at approximately 4:05 A.M. on April 14th and the first outflow was recorded at approximately 6:30 A.M. on April 14th.

Converting 0.39" of rainfall into feet and multiplying by the area of infiltration (1092' x 16'), gives a total precipitation volume of 567.8 ft^3. Outflow meters along the test section measured a total outflow volume of 123.6 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 21.8%.

The last recorded rainfall for this event occurred at approximately 11:00 A.M. on April 14th and the last outflow was recorded at approximately 8:45 A.M. on April 15th. The time to drain was less than one day and would classify as "Good" based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the April 14th rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.16 through Figure 4.19, respectively. Figure 4.20 is a plot of the April 14th rainfall event over the entire asphalt test section.

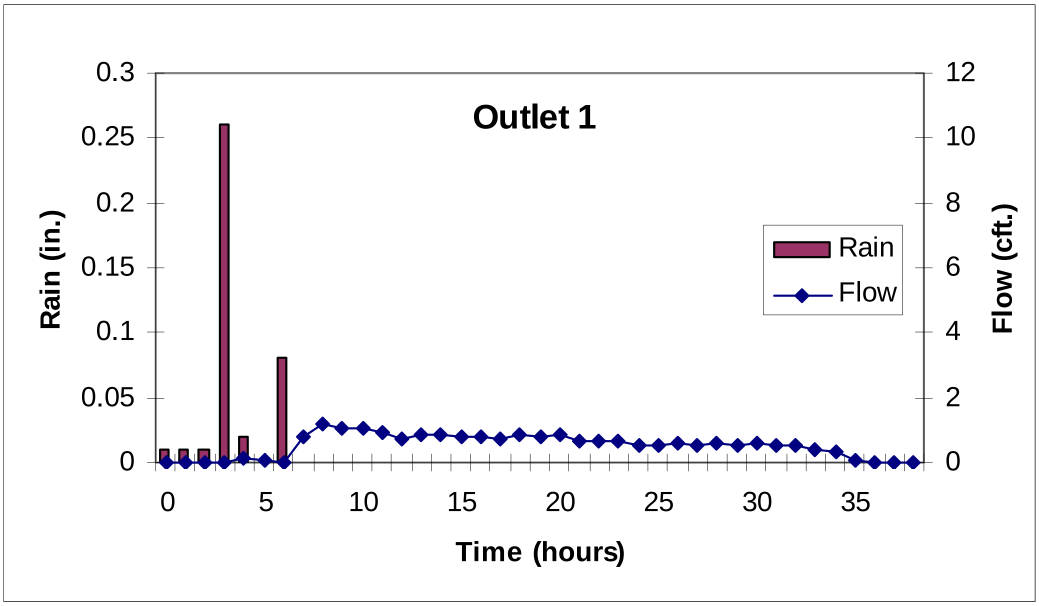

Figure 4.16 First Outlet Data April 14th Event

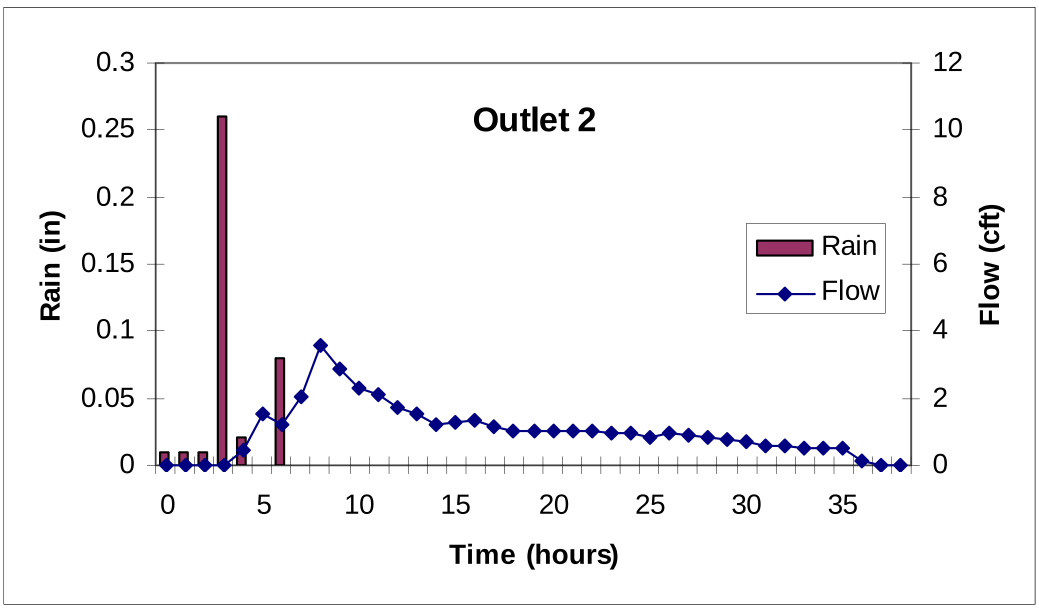

Figure 4.17 Second Outlet Data April 14th Event

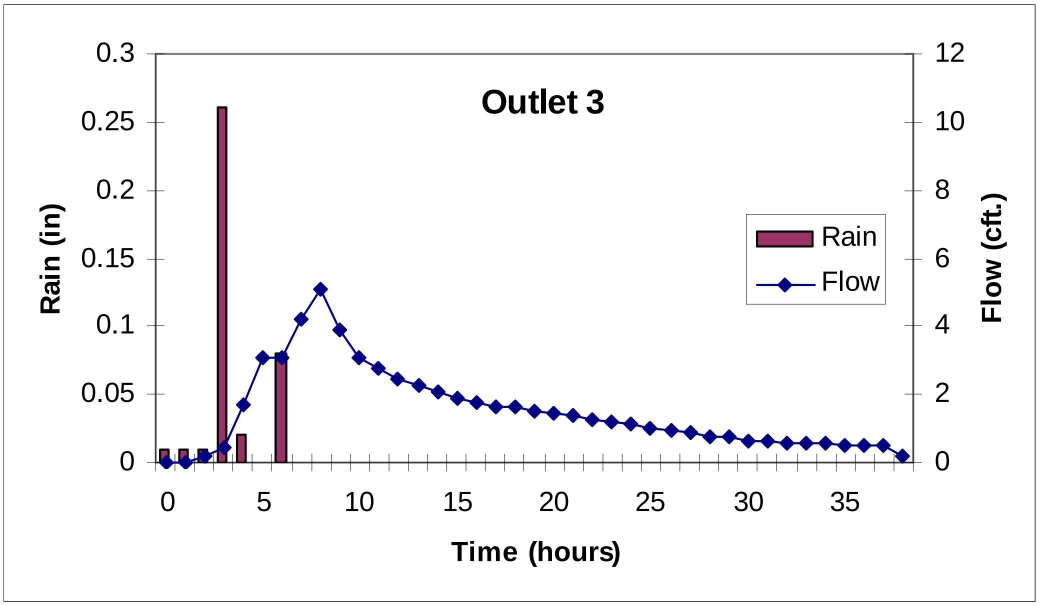

Figure 4.18 Third Outlet Data April 14th Event

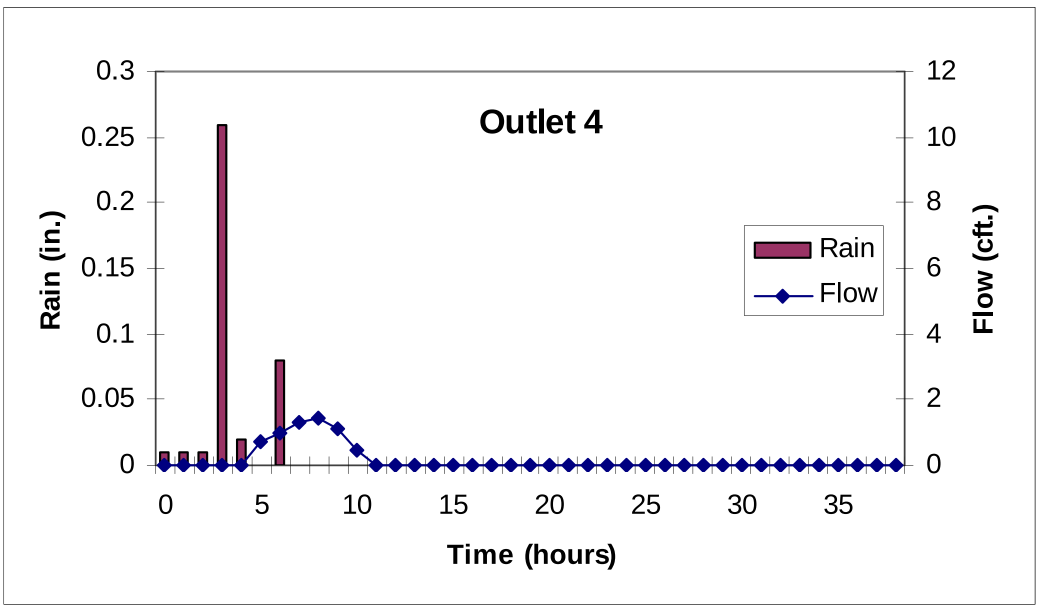

Figure 4.19 Fourth Outlet Data April 14th Event

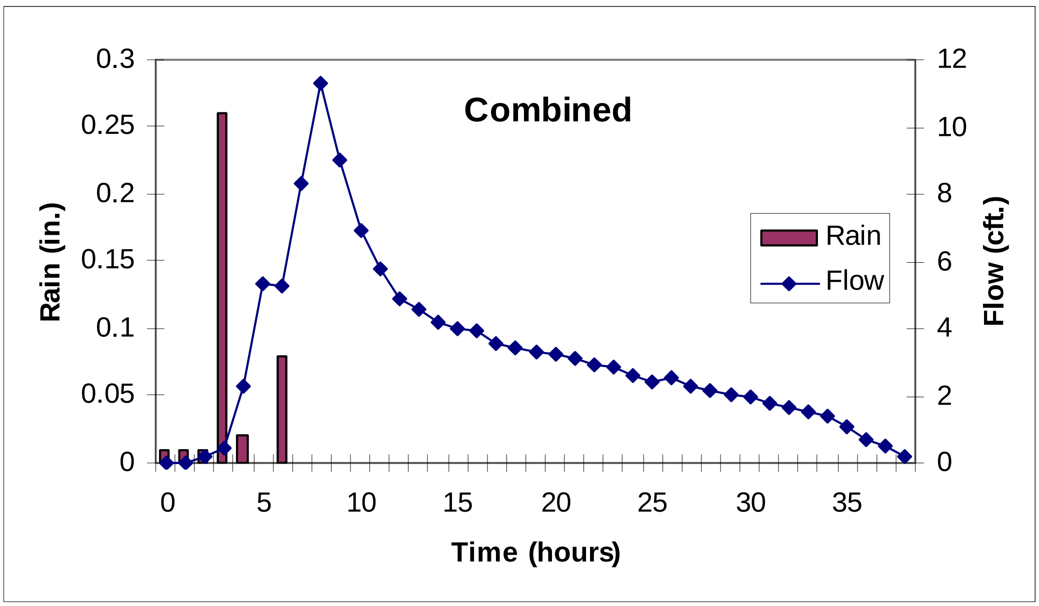

Figure 4.20 Combined April 14th Event for Asphalt Test Section

Asphalt Test Section Observations

Three of the four rainfall events for the asphalt test section produced removal percentages between 20 and 25 percent. The lone exception was the January 31st event which had a removal percentage of 44.9%. Reviewing data suggests that this increase can be attributed to the nature of this rainfall event. The January 31st event lasted for more than a full day. This duration allowed the test section to become saturated and to remain saturated for a substantial period of time. Saturation of the section produced a higher removal percentage than was observed in the other events. Events of shorter duration most likely lost water due to surface runoff and vehicle spray. These losses resulted in lower percentages for the shorter events.

Extremely low outflow volumes were produced from the fourth outlet on the asphalt test section. Profile data for the asphalt test section reveals a discontinuity in the flow path between stations 11+25 and 11+50. A rise in elevation of 0.08’ (1”) occurs in the test section. This rise is enough to impede flow of water in the longitudinal edge drain, resulting in minimal flow from the outlet pipe. Flow from the third outlet was significantly increased as well, suggesting that water unable to drain from the fourth outlet was relieved by the third outlet.

Concrete Test Section

Following is a review of the data collected on the concrete pavement test section. A summary of the results for the concrete test section is provided in Table 4.3 with a more in-depth discussion thereafter. A graphical representation of each rainfall event is provided. It should be noted that the vertical scale changes for each rainfall event in an effort to show detailed trends for each event.

Table 4.3 Summary of Concrete Test Section Results

Concrete Test Section					
PCI Rating: 100 "Excellent"					
Event	Rainfall (cft)	Outflow (cft)	Infiltrated Water Removed (%)	Time to Drain (hours)	AASHTO Rating
19-Jun	1536	51.4	3.3	1.8	Excellent
6-Jul	4181.3	167.2	4	1.5	Excellent
11-Jul	885.3	14.1	1.6	4.5	Good
13-Sep	4906.7	309.7	6.3	2.5	Good

Concrete Section Profile

Survey rod readings for the outside edge of the concrete pavement are given in Table 4.4 on the following page. These readings show elevation changes along the flow path of the water in the collector trench.

Distance measurements between the outlets showed that the drainage system was built to MDOT design specifications. Recall that the specifications dictate that there should be four outlets spaced at 200 feet. For this section the spaces were measured to be exactly 200 feet. The 200-foot measurements were used to calculate the precipitation infiltration area.

Table 4.4 Concrete Profile

Station	Rod Reading
13+75	3.61
14+00	3.61
14+25	3.61
14+50	3.61
14+75	3.60
15+00	3.59
15+25	3.59
15+50	3.60
15+75	3.61
16+00	3.64
16+25	3.66
16+50	3.65
16+75	3.63
17+00	3.63
17+25	3.67
17+50	3.70
17+75	3.71
18+00	3.69
18+25	3.68
18+50	3.69
18+75	3.72
19+00	3.76
19+25	3.80
19+50	3.81
19+75	3.81
20+00	3.81
20+25	3.79
20+50	3.79
20+75	3.79
21+00	3.80
21+25	3.82
21+50	3.84
21+75	3.88

Concrete Pavement Condition Survey

Visual observation of the concrete test section revealed no pavement distresses. Since there were no distresses in the concrete test section, the PCI value is 100. That gives the concrete test section a distress rating of “excellent”.

June 19, 2007, Rainfall Event

Rainfall totaling 1.44” fell on the concrete test section over a 12-hour period. The rain event began at approximately 4:35 A.M. on June 19th and the first outflow was recorded at approximately 7:20 A.M. on June 19th.

Converting 1.44” of rainfall into feet and multiplying by the area of infiltration (800’ x 16’), gives a total precipitation volume of 1536 ft^3. Outflow meters along the test section measured a total outflow volume of 51.4 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 3.3%.

The last recorded rainfall for this event occurred at approximately 2:05 P.M. on June 19th and the last outflow was recorded at approximately 3:55 P.M. on June 19th. The time to drain was less than two hours and would classify as “Excellent” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the rainfall event. The data collected from each individual outlet is shown (in the direction of flow) in Figures 4.21 through Figure 4.24, respectively. Figure 4.25 is a plot of the June 19th rainfall event over the entire concrete test section.

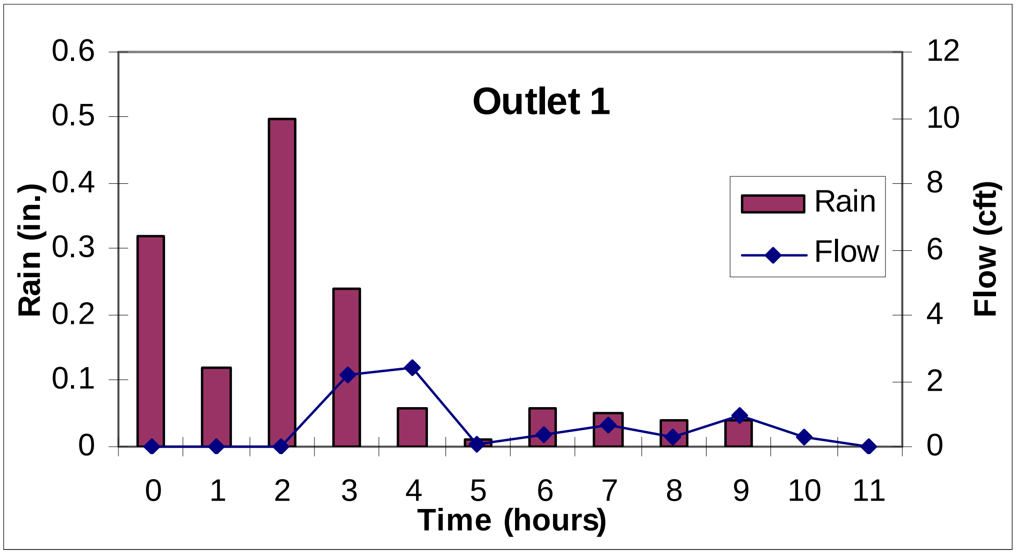

Figure 4.21 First Outlet Data June 19th Event

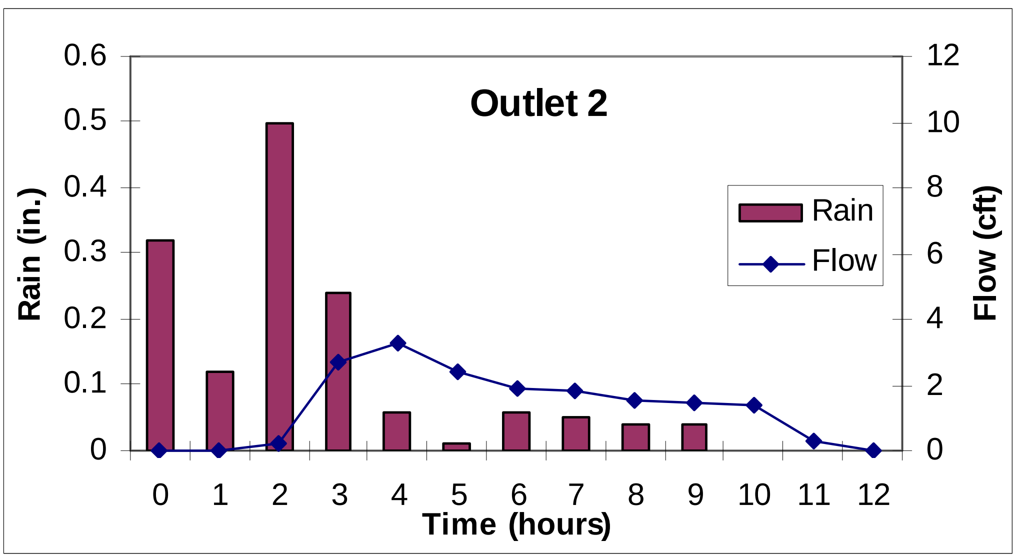

Figure 4.22 Second Outlet Data June 19th Event

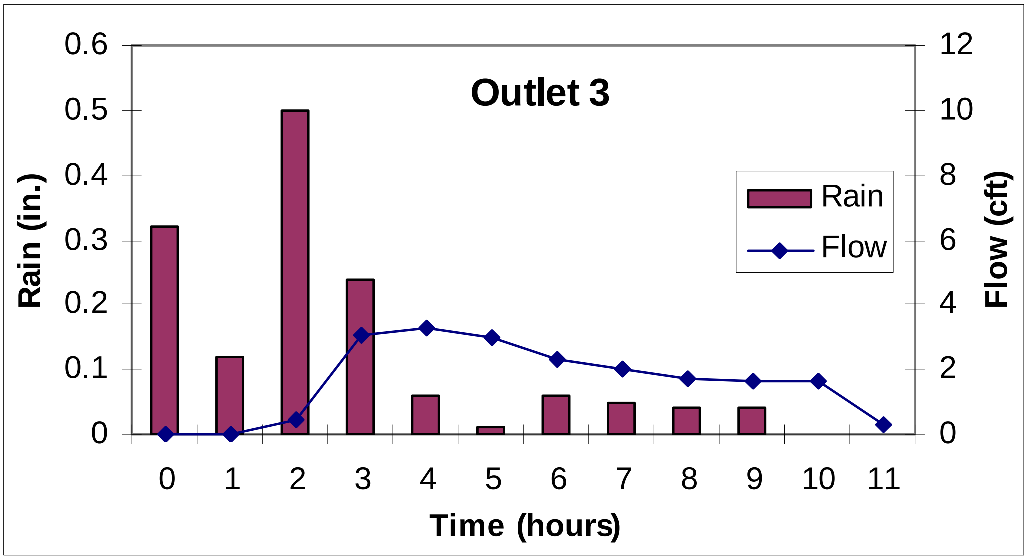

Figure 4.23 Third Outlet Data June 19th Event

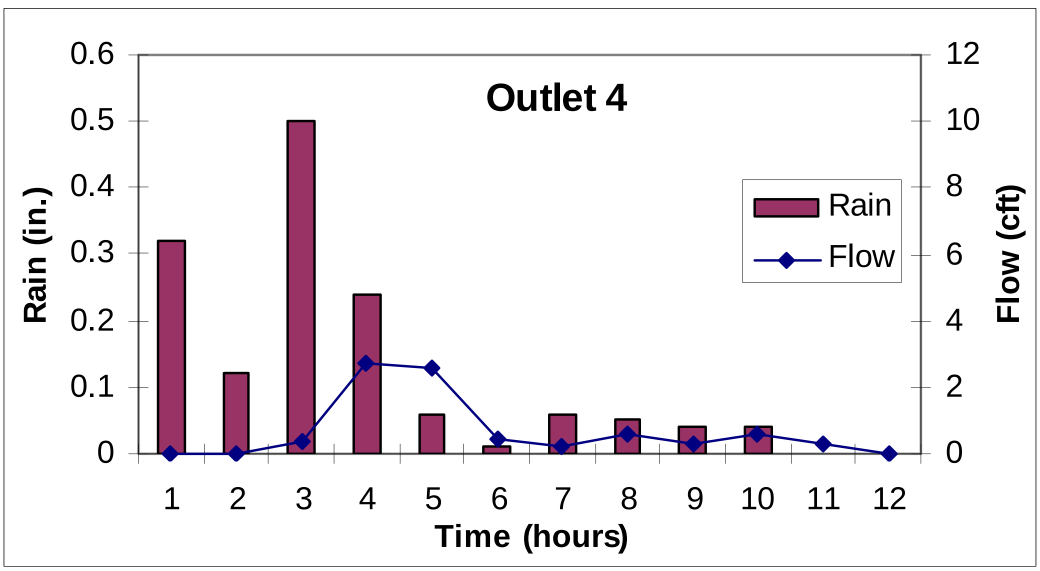

Figure 4.24 Fourth Outlet Data June 19th Event

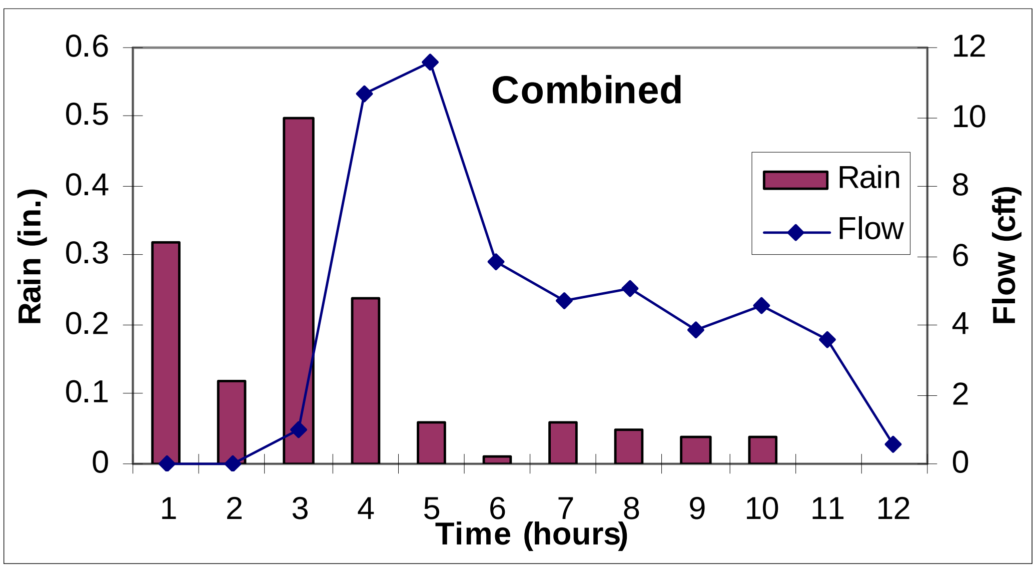

Figure 4.25 Combined June 19th Event for Concrete Test Section

July 6, 2007, Rainfall Event

Rainfall totaling 3.92” fell on the concrete test section over a 21-hour period. The rain event began at approximately 3:15 A.M. on July 6th and the first outflow was recorded at approximately 4:45 A.M. on July 6th.

Converting 3.92” of rainfall into feet and multiplying by the area of infiltration (800’ x 16’), gives a total precipitation volume of 4181.3 ft^3. Outflow meters along the test section measured a total outflow volume of 167.2 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 4.0%.

The last recorded rainfall for this event occurred at approximately 10:10 A.M. on July 7th and the last outflow was recorded at approximately 11:40 A.M. on July 7th. The time to drain was less than two hours and would classify as “Excellent” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.26 through Figure 4.29, respectively. Figure 4.30 is a plot of the July 6th rainfall event over the entire concrete test section.

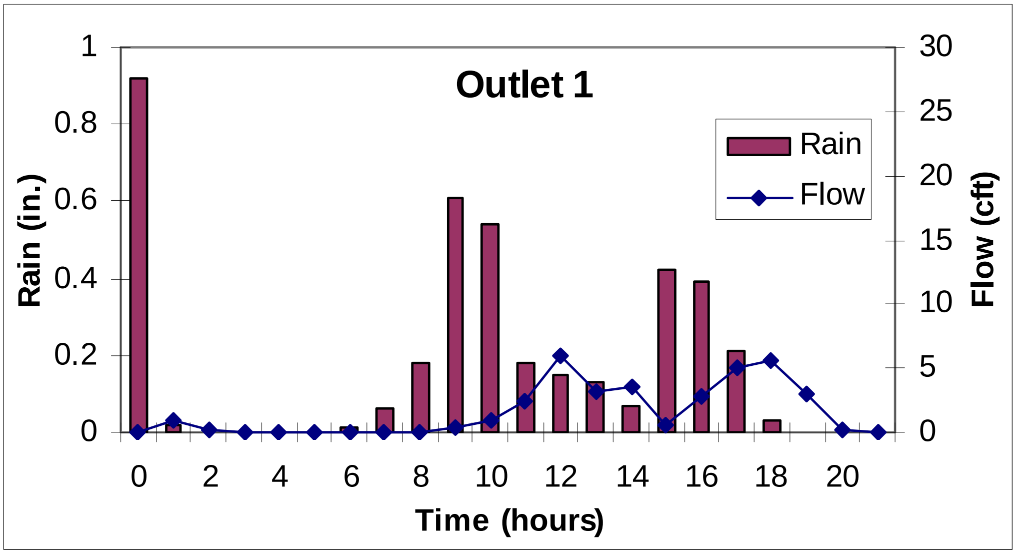

Figure 4.26 First Outlet Data July 6th Event

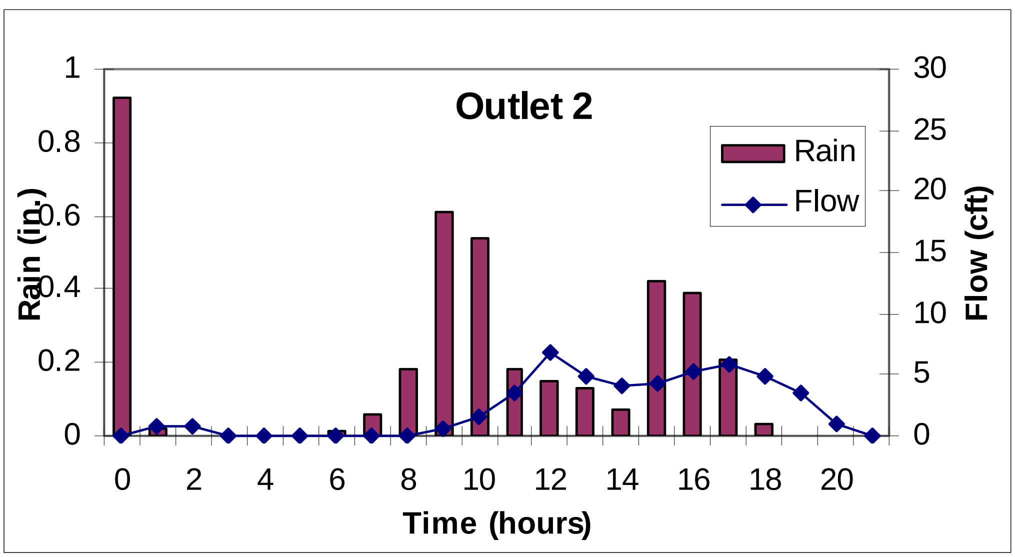

Figure 4.27 Second Outlet Data July 6th Event

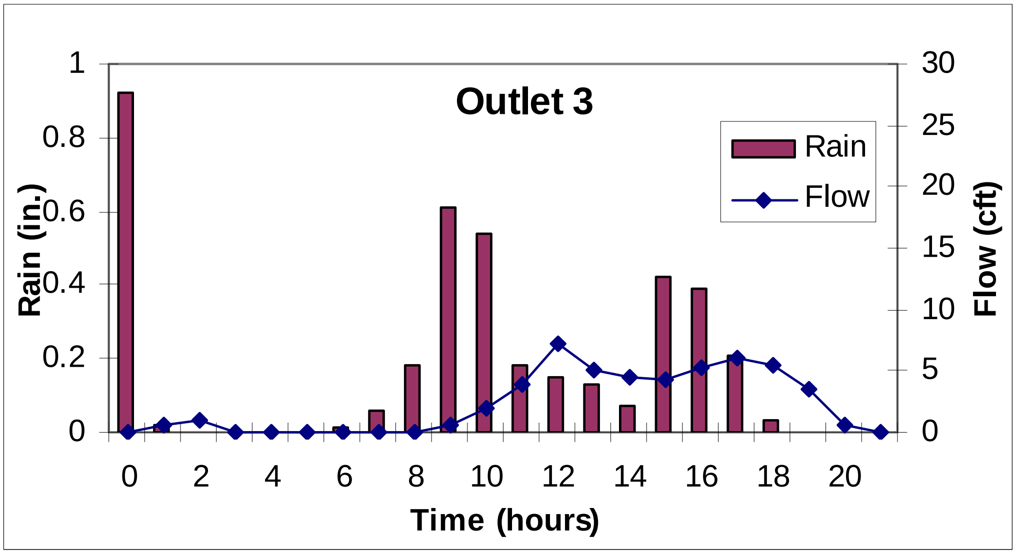

Figure 4.28 Third Outlet Data July 6th Event

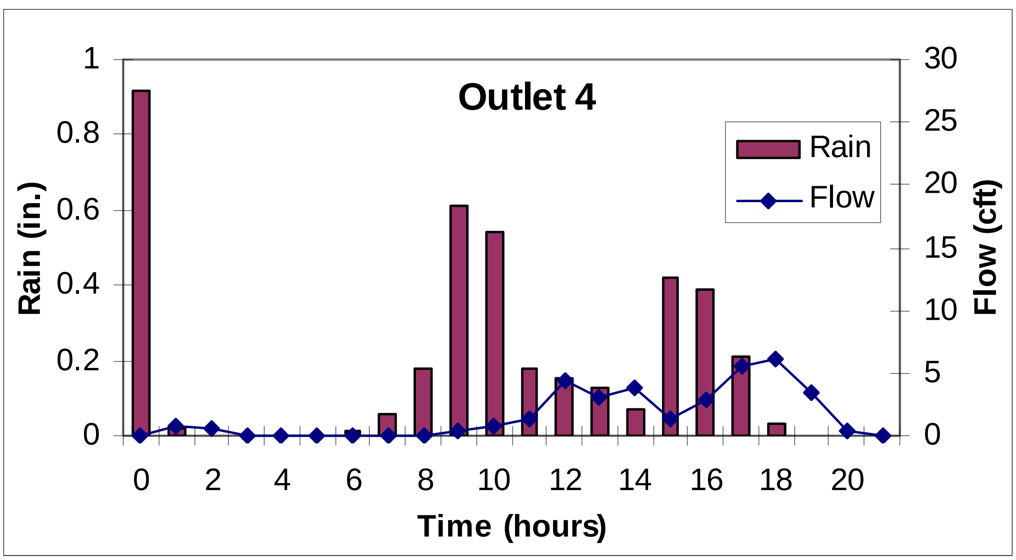

Figure 4.29 Fourth Outlet Data July 6th Event

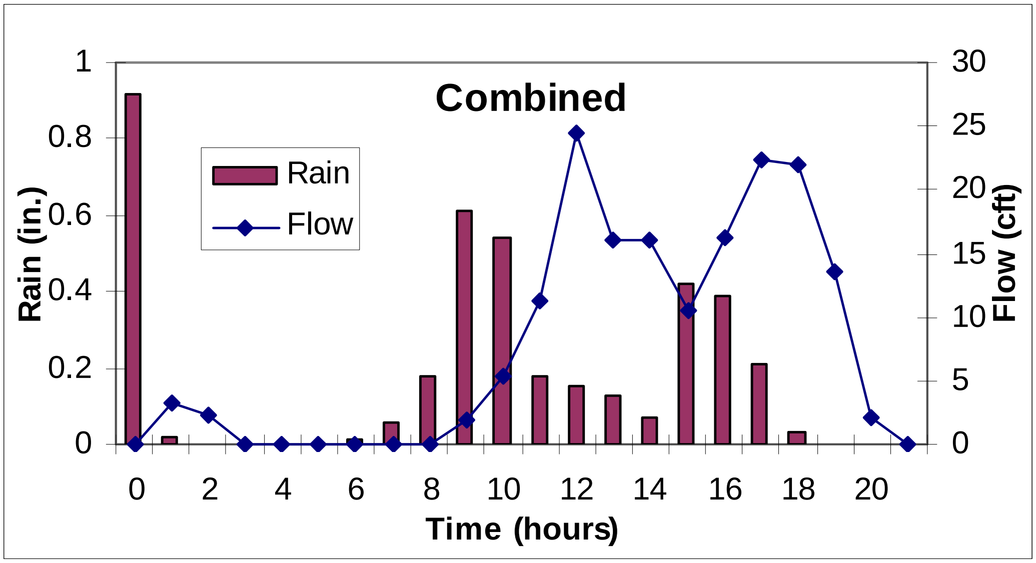

Figure 4.30 Combined July 6th Event for Concrete Test Section

July 11, 2007, Rainfall Event

Rainfall totaling 0.83” fell on the concrete test section over an 11-hour period. The rain event began at approximately 1:50 A.M. on July 11th and the first outflow was recorded at approximately 2:50 A.M. on July 11th.

Converting 0.83” of rainfall into feet and multiplying by the area of infiltration (800’ x 16’), gives a total precipitation volume of 885.3 ft^3. Outflow meters along the test section measured a total outflow volume of 14.1 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 1.6%.

The last recorded rainfall for this event occurred at approximately 6:50 A.M. on July 11th and the last outflow was recorded at approximately 11:15 A.M. on July 11th. The time to drain was less than one day and would classify as “Good” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.31 through Figure 4.34, respectively. Figure 4.35 is a plot of the July 11th rainfall event over the entire concrete test section.

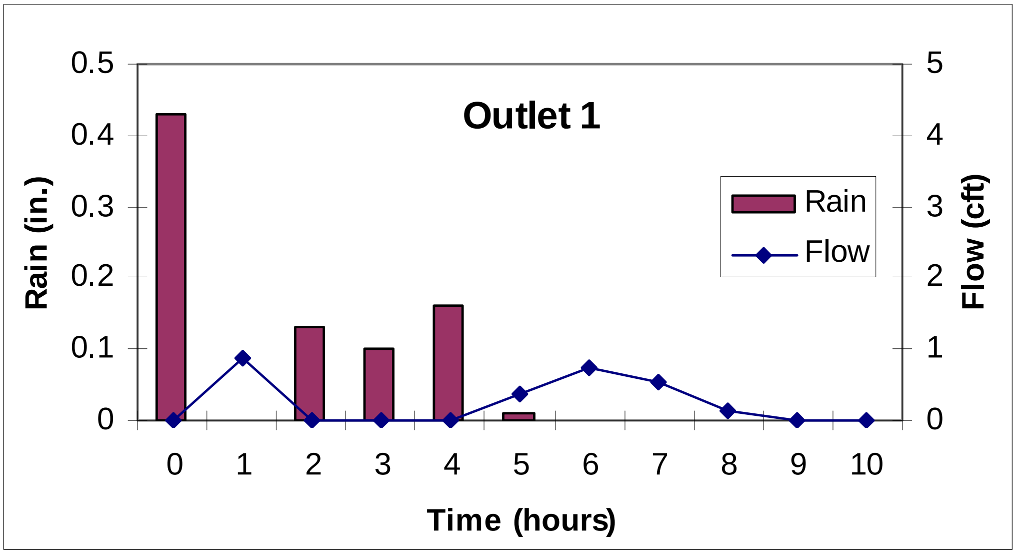

Figure 4.31 First Outlet Data July 11th Event

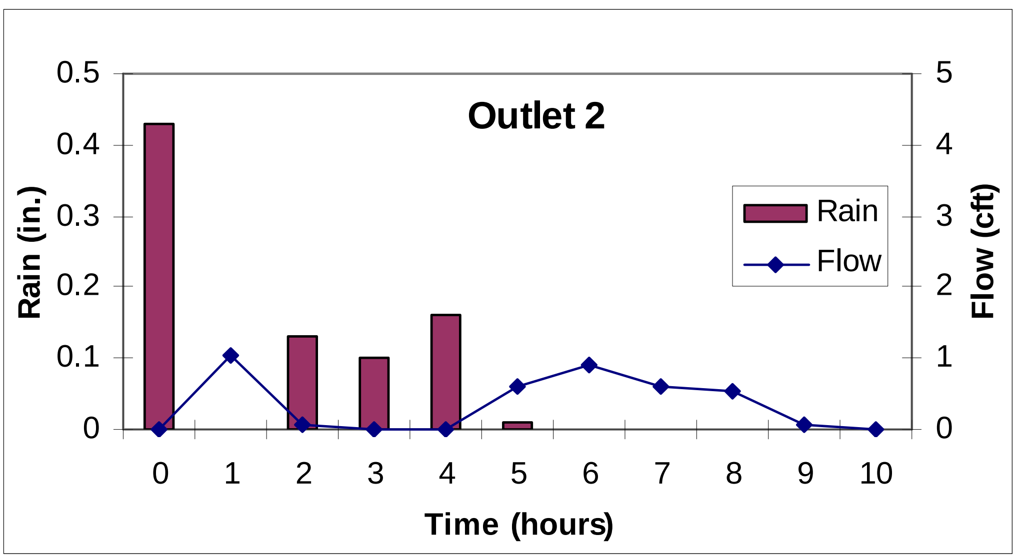

Figure 4.32 Second Outlet Data July 11th Event

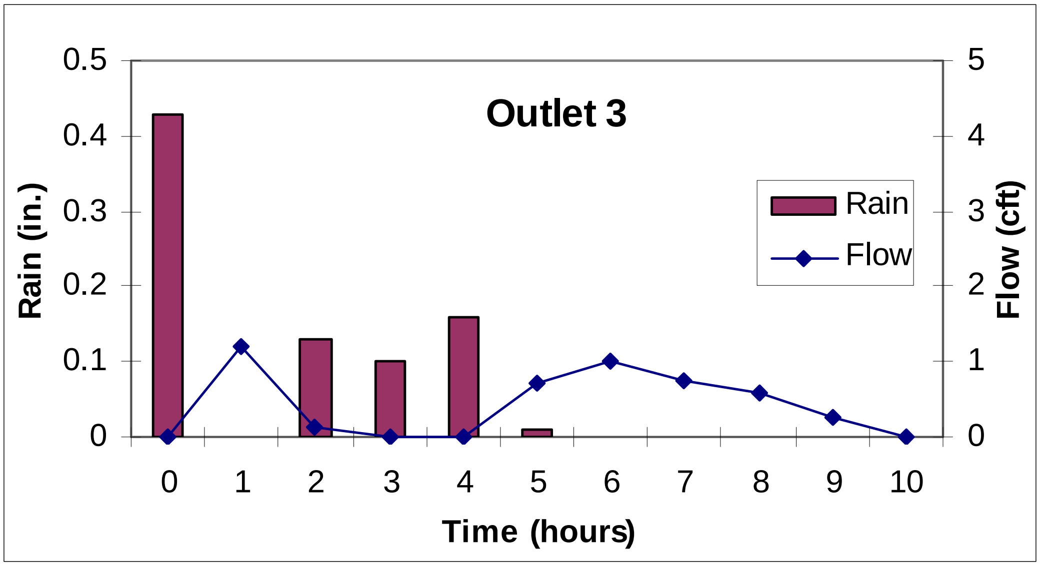

Figure 4.33 Third Outlet Data July 11th Event

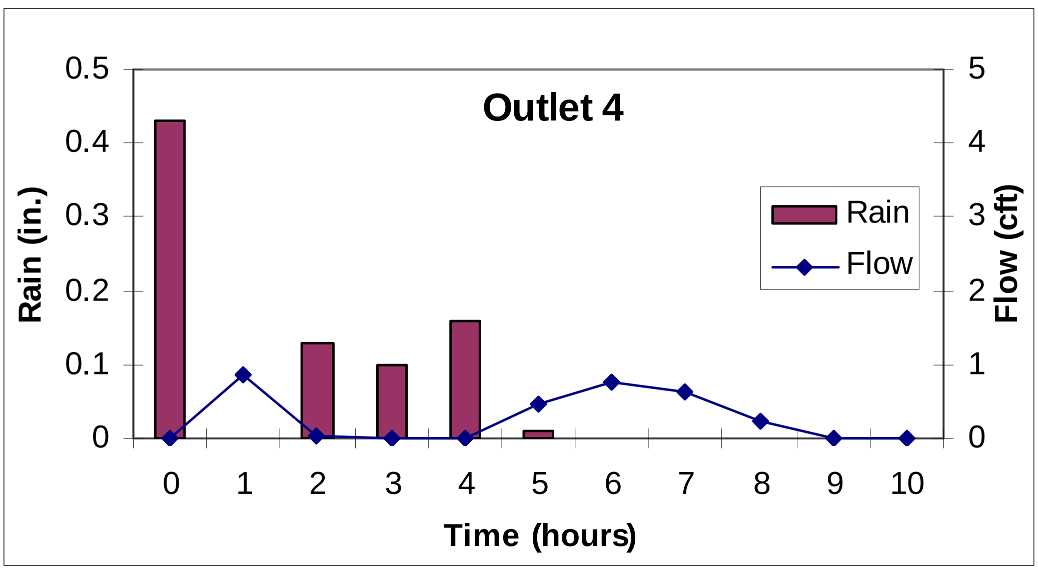

Figure 4.34 Fourth Outlet Data July 11th Event

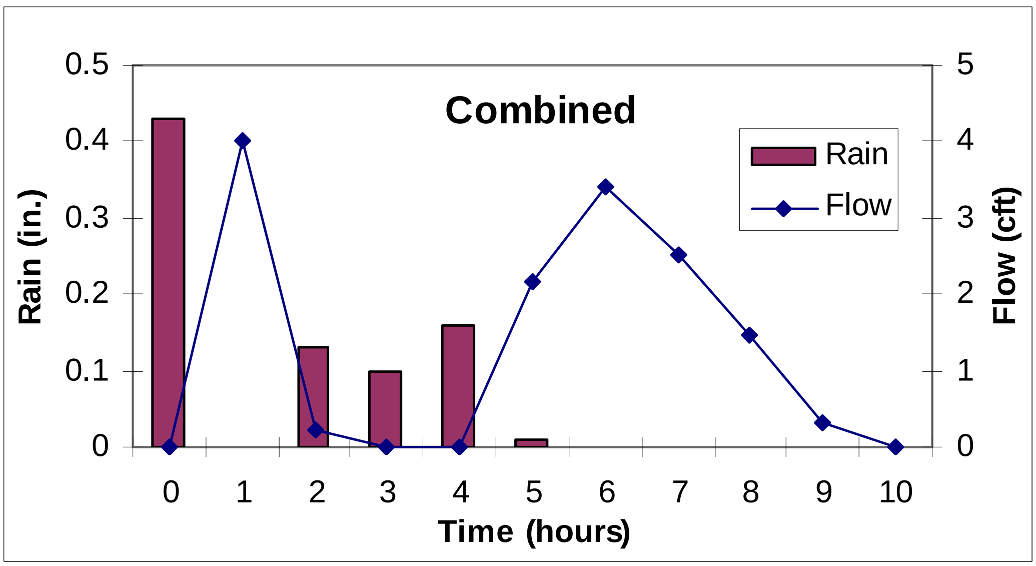

Figure 4.35 Combined July 11th Event for Concrete Test Section

September 13, 2007, Rainfall Event

Rainfall totaling 4.60” fell on the concrete test section over a 17 hour period. The rain event began at approximately 4:25 P.M. on September 13th and the first outflow was recorded at approximately 7:20 P.M. on September 13th.

Converting 4.60” of rainfall into feet and multiplying by the area of infiltration (800’ x 16’), gives a total precipitation volume of 4906.7 ft^3. Outflow meters along the test section measured a total outflow volume of 309.7 ft^3. With these volumes, the infiltrated water removed for this rainfall event was 6.3%.

The last recorded rainfall for this event occurred at approximately 6:55 A.M. on September 14th and the last outflow was recorded at approximately 9:20 A.M. on September 14th. The time to drain was less than one day and would classify as “Good” based on the AASHTO quality of drainage recommendations.

The following figures provide a graphical representation of the rainfall event. The data collected from each individual outlet is given (in the direction of flow) in Figures 4.36 through Figure 4.39, respectively. Figure 4.40 is a plot of the July 11th rainfall event over the entire concrete test section.

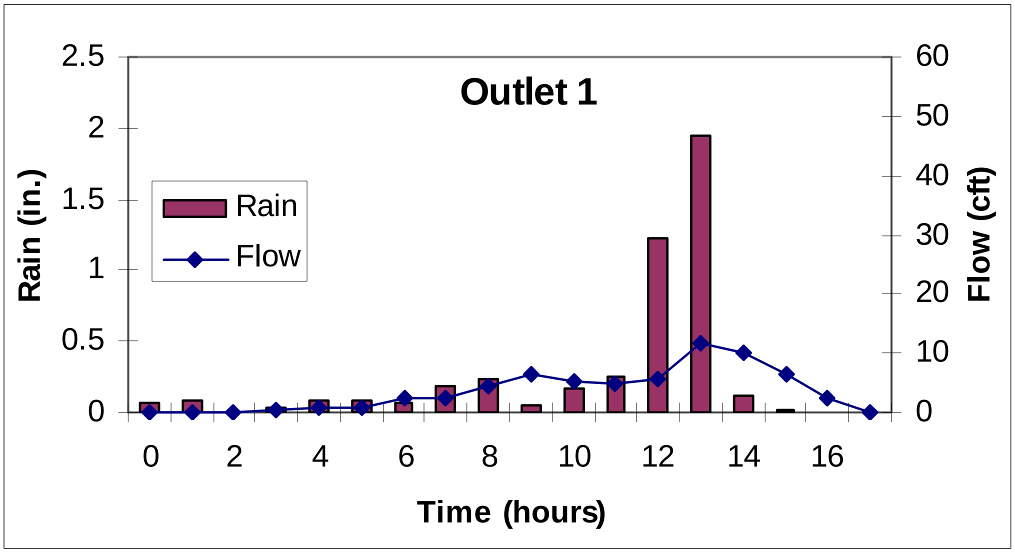

Figure 4.36 First Outlet Data September 13th Event

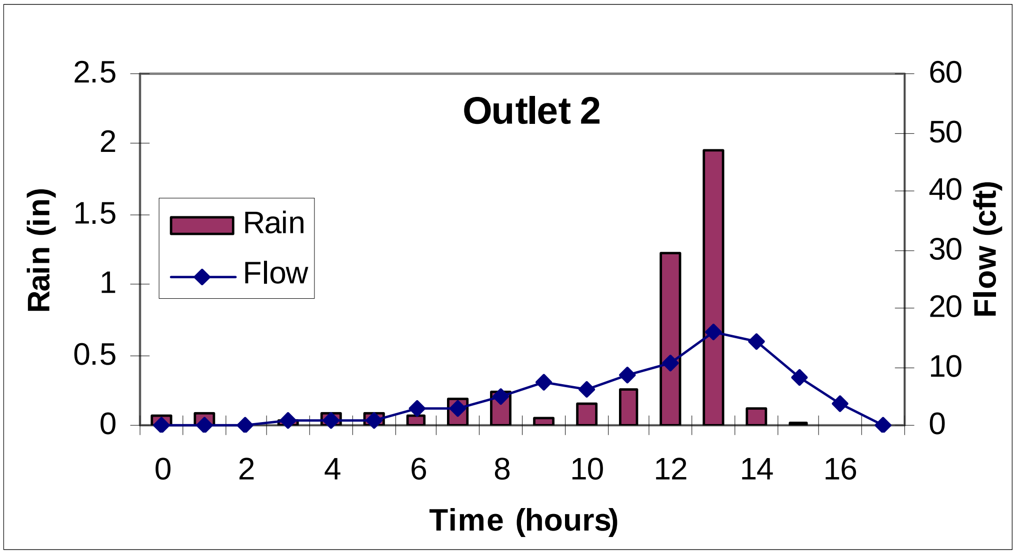

Figure 4.37 Second Outlet Data September 13th Event

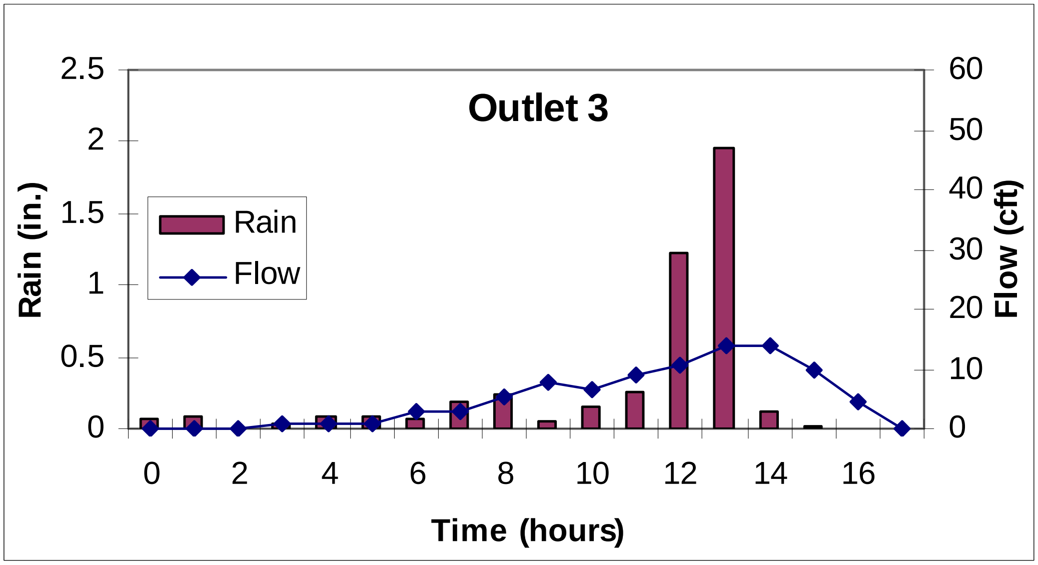

Figure 4.38 Third Outlet Data September 13th Event

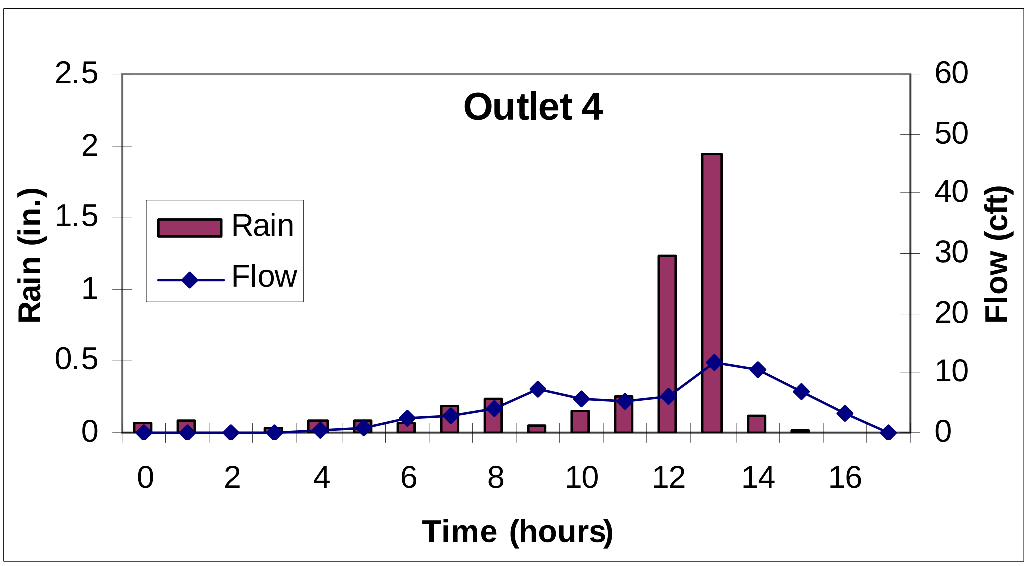

Figure 4.39 Fourth Outlet Data September 13th Event

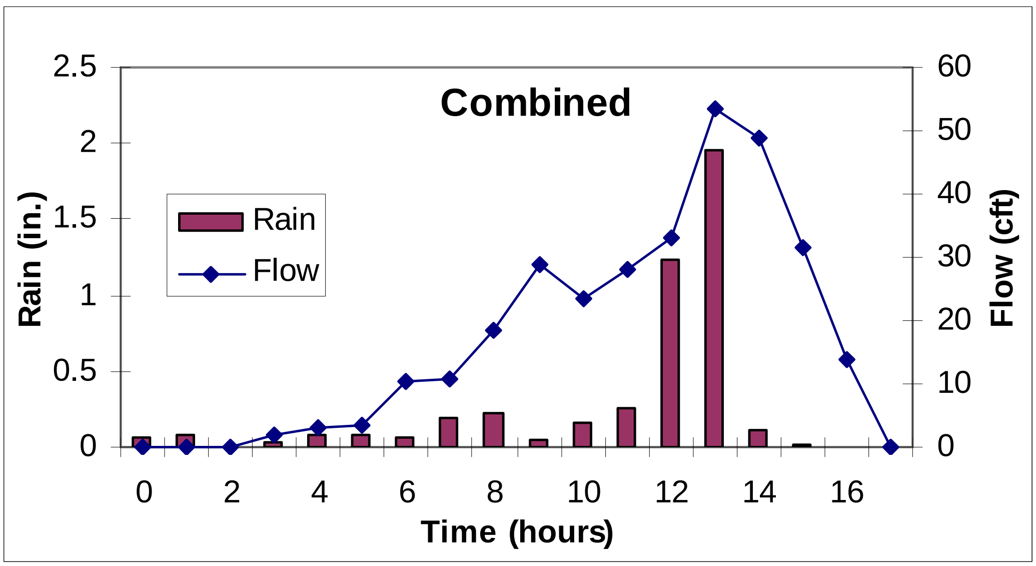

Figure 4.40 Combined September 13th Event for Concrete Test Section

Concrete Test Section Observations

All infiltrated water removal percentages for the concrete test section were found to be less than 10%. Those values are significantly lower than the asphalt test section, despite receiving higher rainfall totals. Lower removal percentages are most likely attributed to the difference in pavement type. More specifically, the concrete is simply not as permeable as the asphalt. The concrete test section contains eleven inches of un-cracked concrete with a PCI of 100 and all joint sealant is in good condition. Very little, if any, water should be entering through the newly constructed concrete pavement. Knowledge gained from the review of literature suggests the most likely source for water entering the concrete pavement drainage system is through the unsealed edge joint between the concrete pavement and the asphalt shoulder. A concrete test section shoulder joint is shown in Figure 4.41 below.

Figure 4.41 Unsealed Edge Joint

Effect of Rainfall

After collecting and reviewing data from both test sections, an effort was made to determine what effect each individual rainfall event had on the corresponding drainage percentages. The first approach used to evaluate this relationship was to plot total rainfall for each event against its corresponding drainage percentage. A plot demonstrating this method on the asphalt test section is given in Figure 4.42 below.

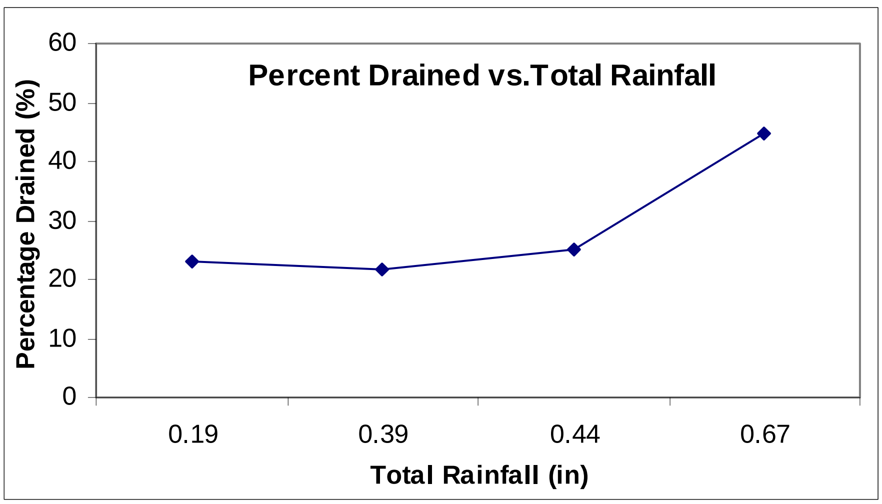

Figure 4.42 Asphalt Percentage Drained vs. Total Rainfall

Figure 4.42 shows that as the total rainfall for the events increased; the percentage of water removed also increased. After some thought, however, it was determined that total rainfall may not show an accurate relationship between the rainfall events and drainage percentages. A method was needed that could account for more aspects of the rainfall event such as duration and intensity.

Average rainfall intensity was calculated for each rainfall event by dividing the total rainfall for the event by the hours of duration. Percentage drained was then plotted against average rainfall intensity. This plot is provided in Figure 4.43 below.

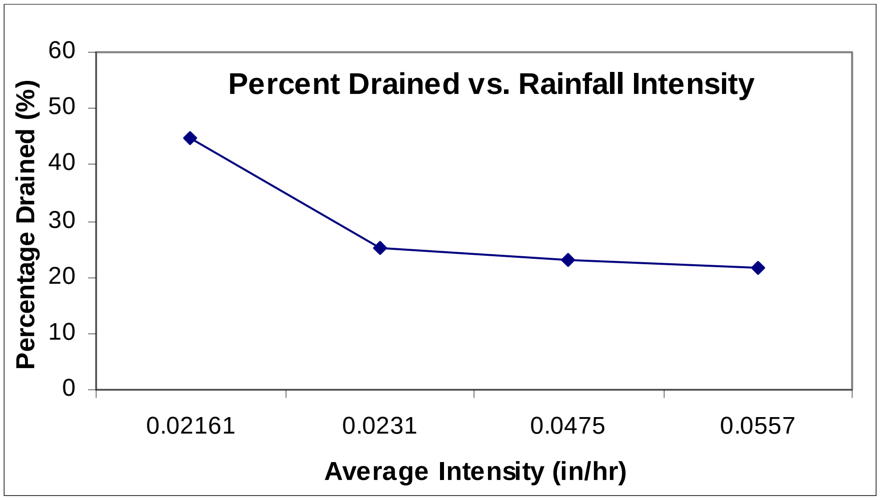

Figure 4.43 Asphalt Percentage Drained vs. Rainfall Intensity

Figure 4.43 shows that as average rainfall intensity increased, the percentage drained from the section decreased. This plot lends itself to the idea that as the intensity increases, surface runoff may also increase, thus reducing the drainage percentages. In other words, a slow soaking rain may is likely to have a higher drainage percentage than a quick heavy shower. The asphalt test section data as shown in Figure 4.43 demonstrates this phenomenon.

Plotting data for the concrete test section using both methods described above produces Figures 4.44 and 4.45 on the following page.

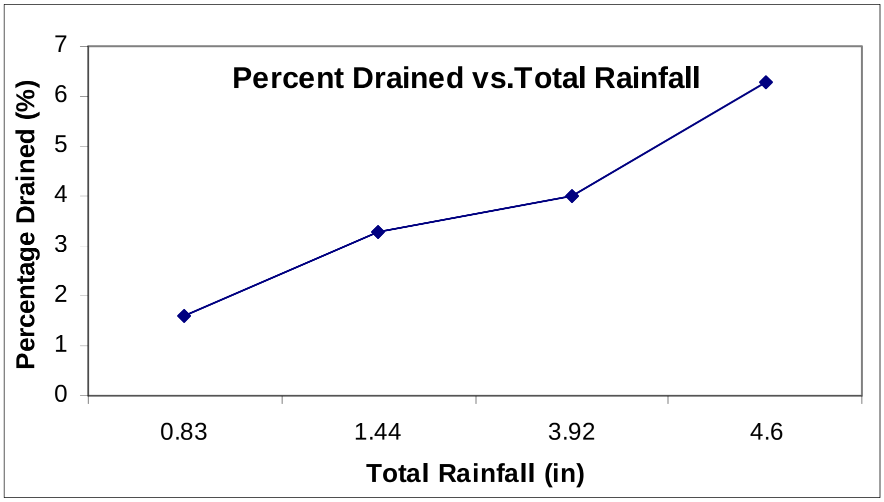

Figure 4.44 Concrete Percentage Drained vs. Total Rainfall

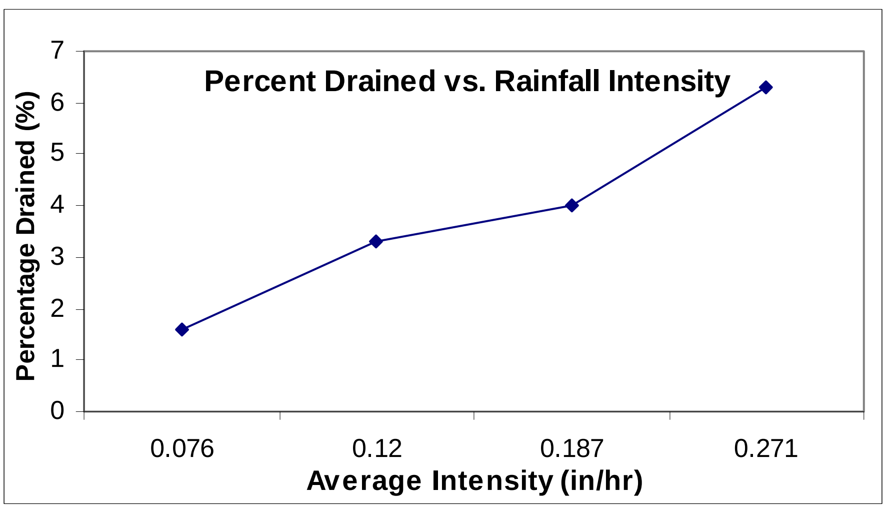

Figure 4.45 Concrete Percentage Drained vs. Rainfall Intensity

Data for the concrete test section showed an increase in percentage drained when total rainfall increased as well as when rainfall intensity increased. This is likely due to the previously discussed infiltration of water into the concrete test section through the unsealed edge joint. For the asphalt test section surface runoff detracts from the percentage drained. However, for the concrete test section surface runoff makes its way into the edge joint and thus into the concrete test section subdrainage system. This would explain the discrepancy between the rainfall intensity plots of the concrete and asphalt test sections.

These plots were created in an effort to describe how differing rainfall events might affect the observed drainage percentages. While these plots provided some useful information, other variables that were not monitored during this study should be considered for constructing an accurate model. Some of these variables include permeability data, pavement moisture content at time of rainfall, temperature, surface runoff volumes, and pavement storage capacity (i.e., how much water is contained in the pavement before water will drain).

Maintenance Survey Responses

Responses to the maintenance questionnaire were obtained from twenty-one transportation agencies. Twelve of the twenty-one agencies reported utilization of edge drain systems; however, only five of those twelve reported having a maintenance plan for these systems. These five responses are summarized below.

1. Kansas – Includes annual inspection of edgedrains as a performance measure for maintenance crews.
2. West Virginia – Specific instructions for inspecting and cleaning edgedrains are included in their agency's maintenance manual.
3. Maryland – Includes cleaning of edgedrains in their maintenance contracts as needed.
4. Wyoming – Conducts annual inspection of edgedrains.
5. Arkansas – Provides maintenance crews with a memo documenting step by step procedures for maintaining edge drain systems. The steps are as follows (24):

    - Log sections of interstate with edgedrains by log mile and establish a predetermined schedule for inspection and cleaning.
    - Spray 3" to 6" around the outlet protectors every year during the growing season with Roundup and clean the screens and troughs of the outlet protectors if needed.

- Inspect a minimum of 10% of the edgedrains with video equipment every two years. If problems are found at any location, clean that section and inspect and clean adjacent sections until no other problem exists. The anticipated number of miles requiring cleaning may warrant purchasing a flushing trailer for your district.
- Inspect 100% of the edgedrains with video equipment by contract on the 10th year of service. The contracts are to include flushing as required based on results from video inspection.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions that can be reached upon completion of this research study include the following:

1. Based on the AASHTO time to drain recommendations; it can be concluded that with ratings of “excellent” or “good” for each rainfall event, the subsurface drainage systems instrumented in this study are functioning efficiently.
2. Performance of these newly constructed subsurface drainage systems suggests that AASHTO time to drain recommendations may be too stringent. More specifically the asphalt test section contained a newly constructed system with minimal outlet spacing free of all obstructions, and the average time to drain for all rainfall events was 22 hours. This was also the case in the study where Hassan (9) instrumented a new system in Indiana. Drainage times for that study ranged from 13 hours to 47 hours depending on the rainfall event.

3. Early percentage of water removed from the subdrainage system beneath the asphalt pavement is significantly greater than the percentage of water removed from the subdrainage systems beneath concrete pavement. Newer concrete pavements may not exhibit the full performance value of a subsurface drainage system. Literature suggests this value will most likely be seen once the pavement becomes distressed (i.e. cracked).
4. Performance data from the edgedrains in the asphalt test section show that an outlet spacing greater than 200 feet will provide adequate drainage.
5. No specific inspection or maintenance schedule is currently followed by MDOT. This could impede the performance of the subsurface drainage system.

Recommendations include:

1. An increase in outlet spacing is recommended for MDOT subsurface drainage systems. This would decrease the initial cost of installation as well as reduce the number of outlets requiring maintenance. The increase in outlet spacing can be based on the maximum distance that can be traversed by inspection and cleaning equipment.
2. Engineering judgment should be used when considering the quality of drainage assigned to a pavement for AASHTO design purposes.

3. All edgedrain outlets should be marked for maintenance purposes.
4. Edge joints between concrete pavements and asphalt shoulders should be sealed to reduce rainfall infiltration.
5. MDOT should implement an inspection and maintenance schedule for pavement subdrainage systems. One strategy to consider is that of the Arkansas Highway Department. A copy of the official maintenance memorandum provided by the state maintenance engineer of Arkansas is shown in Appendix C.

Areas for further research include:

1. Non-destructive (FWD) testing of MDOT pavement sections with and without subsurface drainage to quantify the effect subsurface drainage has on subgrade modulus.
2. Long term monitoring of drained pavement sections to identify trends, tendencies, and long range effectiveness/benefits.
3. A larger scale drainage study of precipitation vs. outflow and moisture content. The study should include pavements of different age, conditions, and subgrade materials in an effort to determine the effect each may have on pavement subdrainage.

4. A study to determine what effect rainfall intensity has on the percentage of water drained from the system. Many factors should be accounted for in this study, including, but not limited to:

    - Time of day
    - Air temperature/weather conditions
    - Surface runoff
    - Traffic spray
    - Pavement permeability
    - Storage of pavement (how much rainfall is held internally before drainage is seen)
    - Rainfall total and duration

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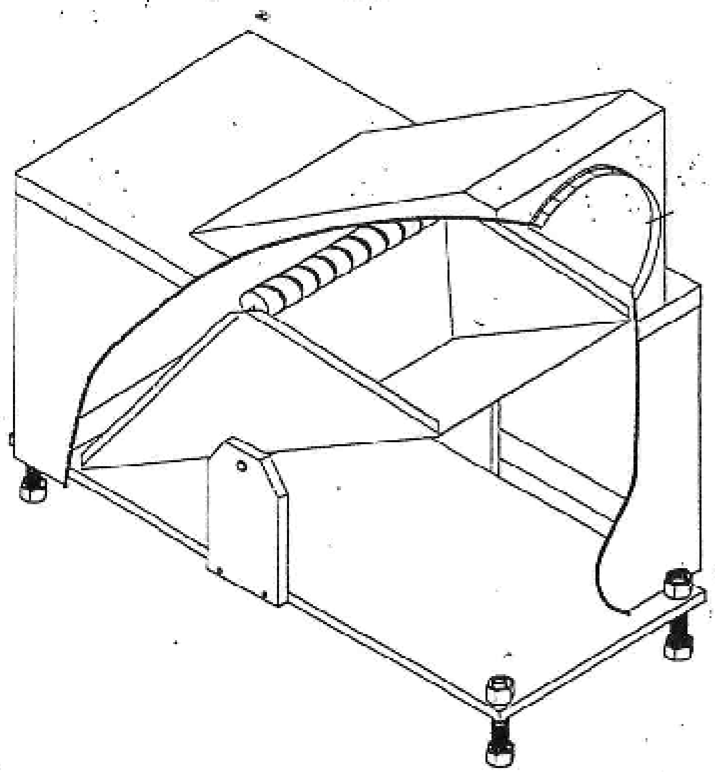
(24) Sullivan, Pat, Personal Correspondence, Arkansas State Highway and Transportation Department, September, 2007.

APPENDIX A

OUTFLOW BUCKET INFORMATION

MODEL TB-89

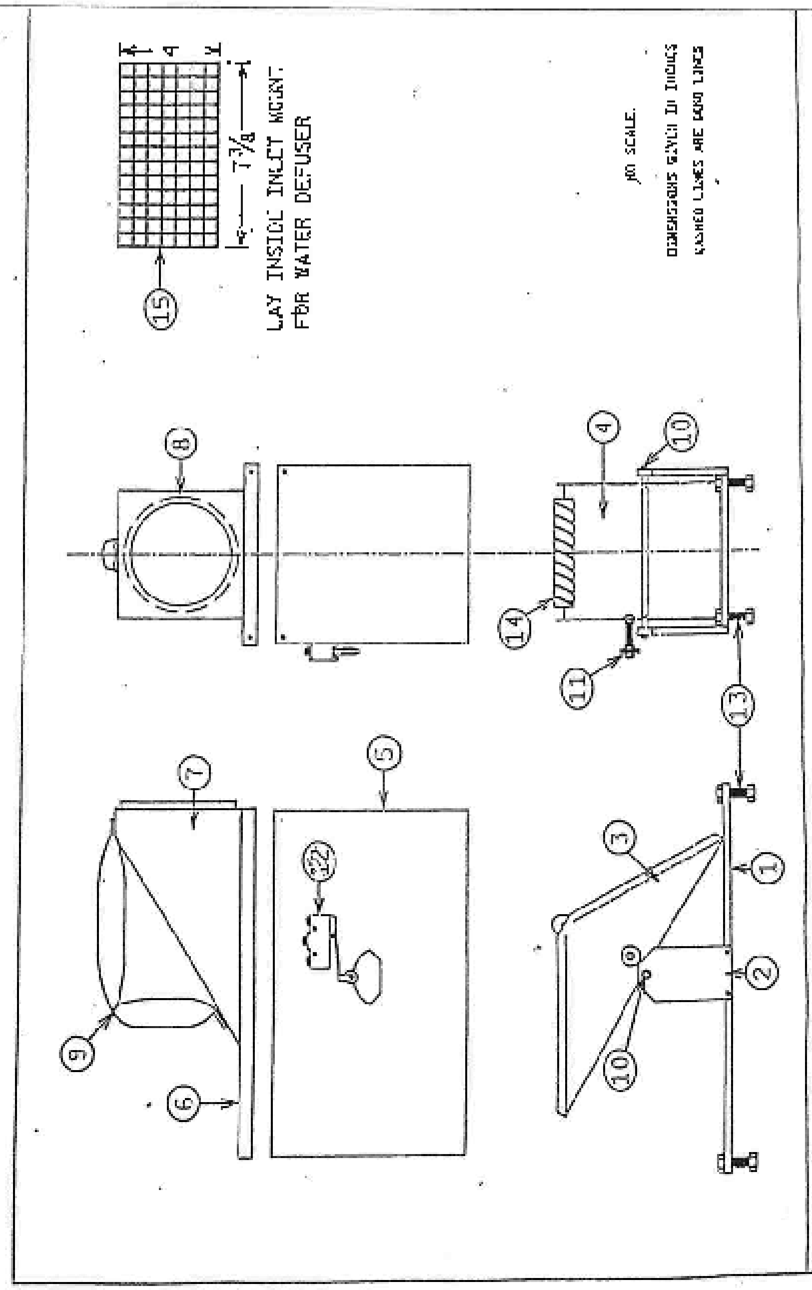


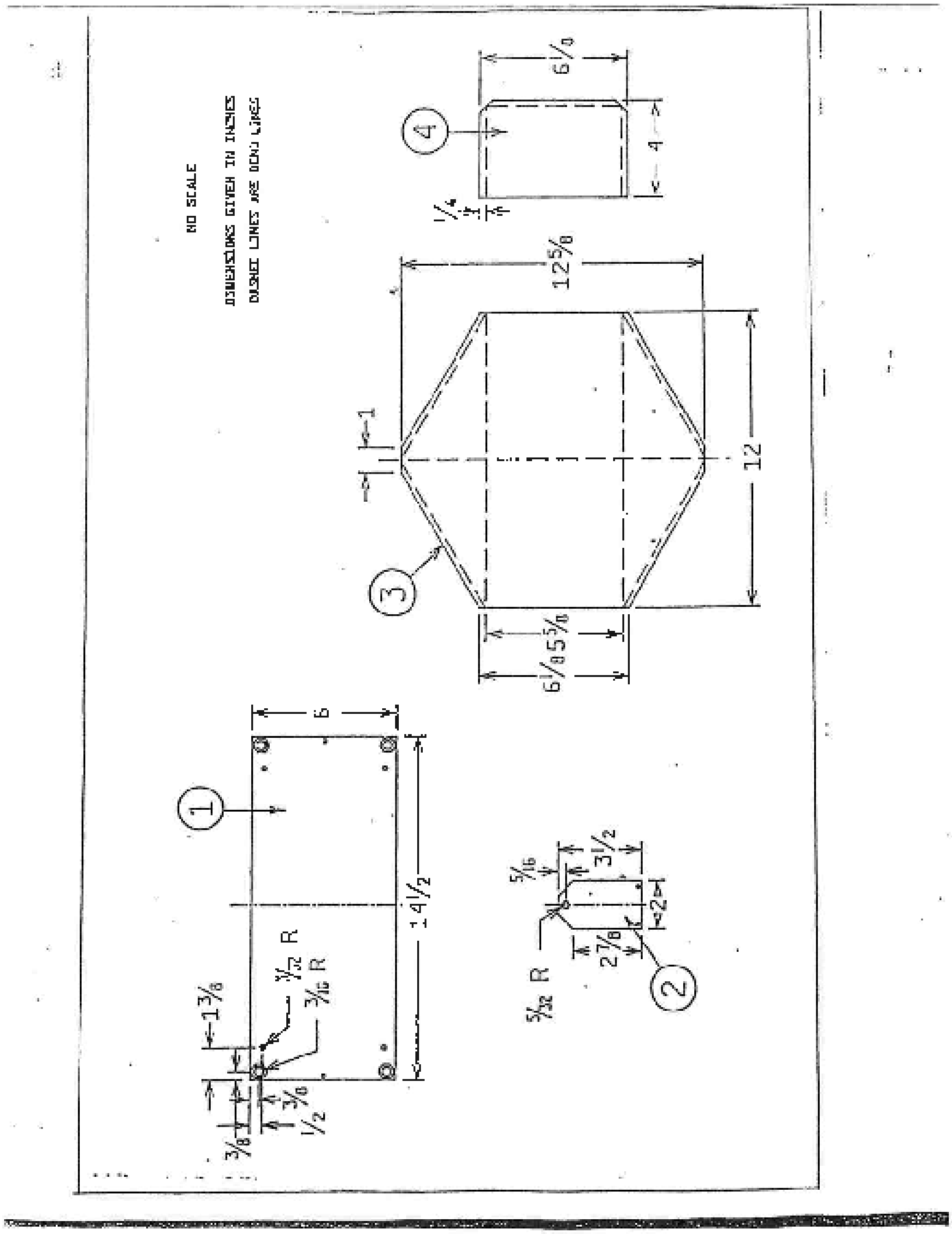
WISCONSIN DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS AND TRANSPORTATION SERVICES
BUREAU OF ENGINEERING OPERATIONS
CENTRAL OFFICE MATERIALS
APPLIED RESEARCH SECTION

DESIGN & CONSTRUCTION
BY
ROGER M. PECK
RESEARCH PROJECT TECHNICIAN

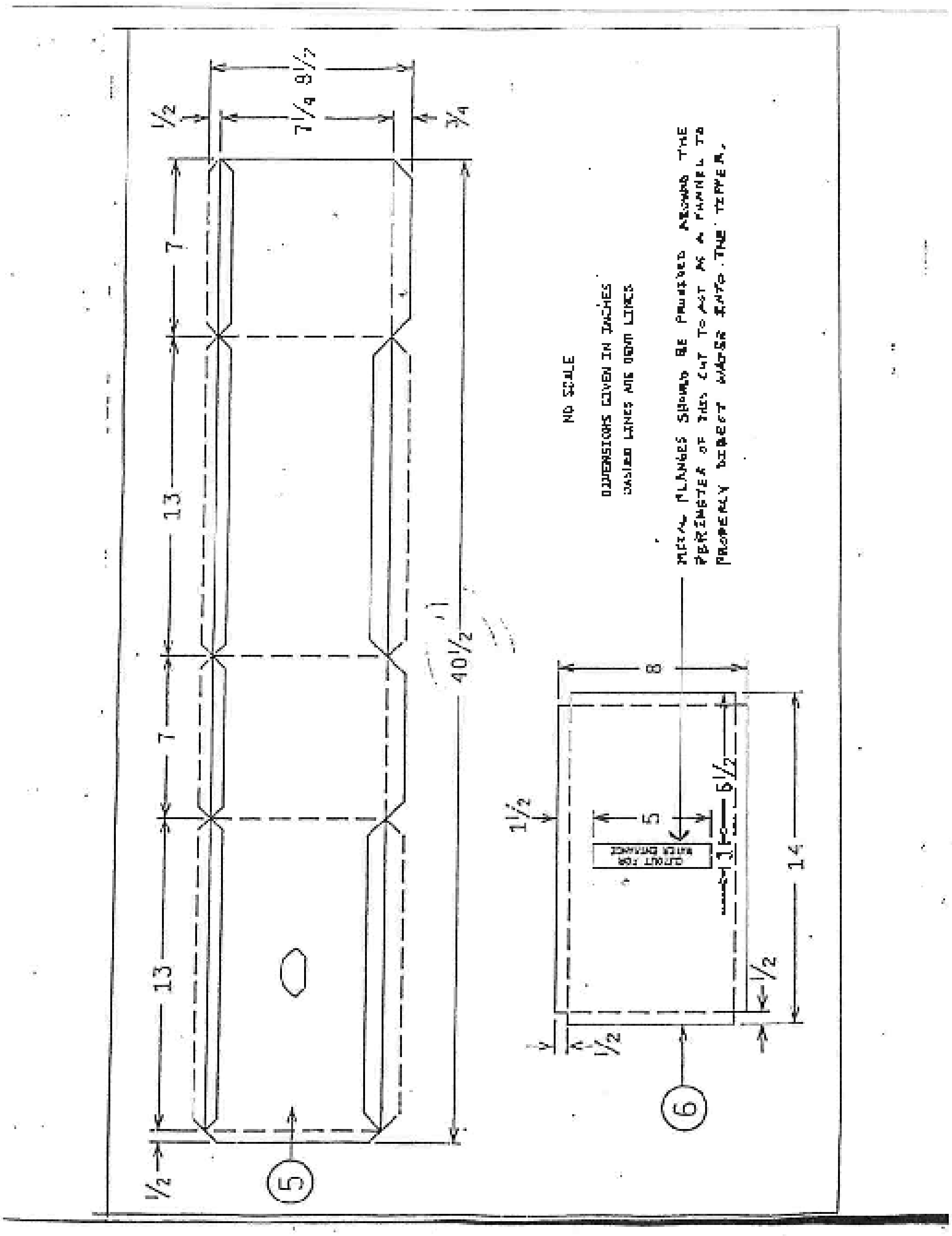
MATERIALS LIST

1. BOTTOM PLATE 11½' X 6" X¼" ALUM.
2. BUCKET SUPPORTS 2" X 3 15/16" X¼" ALUM.
3. BUCKET 12" X 12⅝" X 22 ga. GALV. STEEL
4. BUCKET DIVIDER 6⅓" X 4" X 22 ga. GALV. STEEL
5. SIDE WALL (S) 40½" X 8½" X 22 ga. GALVANIZE STEEL.
6. TOP 14' X 8" X 22 ga. GALV. STEEL
7. INLET MOUNT 12⅞" X 11¾" X 22 ga. GALVANIZE STEEL
8. INLET FACE 6' X 5" X 22 ga. GALV. STEEL
9. ¾" THIN WALL GALVANIZE CONDUIT
10. 6½X¼" BRASS ROD (SOLDER TO CENTER - BOTTOM OF BUCKET)
11. MICRO TRIP LEVER ⅜" X 1½" BOLT WITH NUT(S) & WASHERS
12. MICRO SWITCH (BZ - 2RW 82-A2 HONEYWELL)
13. ⅜" X 1½" CARRIAGE BOLTS WITH NUTS
14. 9" X # 6 RE-BAR COUNTER BALANCE
15. 7⅜" X 6" X ⅜" PLASTIC DEFUSER GRILL


LAY INSIDE INLET MOUNT
FOR WATER DEFUSER
7 3/8
4
NO SCALE.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15



NO SCALE
DIMENSIONS GIVEN IN INCHES
DASHED LINES ARE BEND LINES


NO SCALE
DIMENSIONS GIVEN IN INCHES
DASHED LINES ARE BENT LINES
METAL FLANGES SHOULD BE PRESSED AROUND THE PERIMETER OF THIS CUT TO ACT AS A FUNNEL TO PROPERLY DIRECT WATER INTO THE TIPPER.
CUTOUT FOR WATER ENTRANCE
5
6

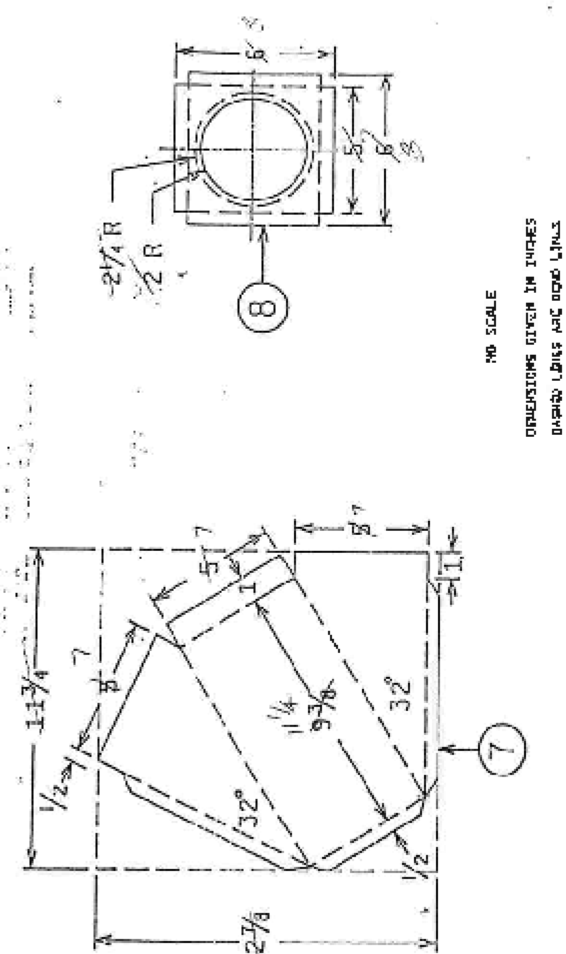

NO SCALE
DIMENSIONS GIVEN IN INCHES
DASHED LINES ARE BEND LINES
8
7
2 1/4 R
1/2 R
32°
32°
9 3/8
11 3/4
12 7/8
1/2
1/2
1

Table A.1 Outflow Bucket Calibration

Outflow Bucket Calibration									
Bucket 1		Bucket 2		Bucket 3		Bucket 4		Bucket 5	
Side 1	Side 2	Side 1	Side 2	Side 1	Side 2	Side 1	Side 2	Side 1	Side 2
885	815	910	880	835	860	835	925	860	890
900	820	900	890	845	855	840	930	875	900
890	810	905	885	840	855	850	920	870	890
Avg. = 850 mL		Avg. = 895 mL		Avg. = 850 mL		Avg. = 880 mL		Avg. = 880 mL	

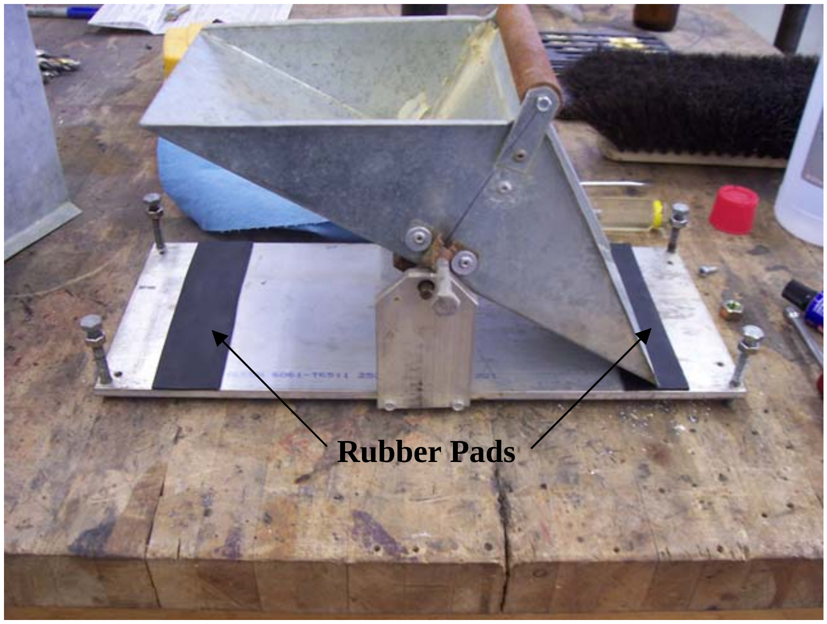


Figure A.1   Rubber Pads

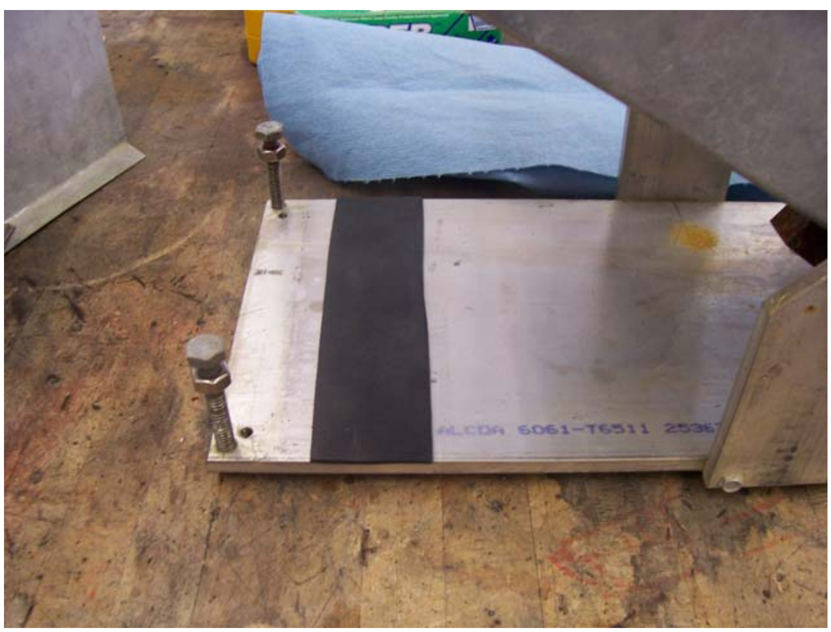


Figure A.2   Rubber Pad Close View

Figure A.3   Flange for Funneling Water

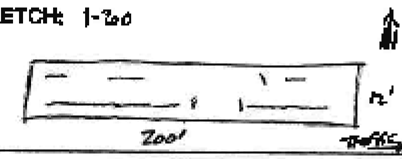
APPENDIX B

PCI SURVEY SHEETS

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH Oklahoma SECTION 82 SAMPLE UNIT 1
SURVEYED BY JW DATE 6/3/07 SAMPLE AREA 2400 ft²

SKETCH: 1-20



1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

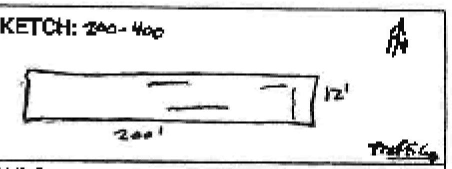
DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
10 L	11	94	16	4	5	5	37	5		177	7.4	14

PCI= 86

ASPHALT SURFACED ROADS AND PARKING LOTS
CONDITION SURVEY DATA SHEET
FOR SAMPLE UNIT

BRANCH Oktibbeha SECTION 02 SAMPLE UNIT 2
SURVEYED BY JW DATE 6/3/07 SAMPLE AREA 2400 ft²

SKETCH: 200-400



1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
10L	5	29	4	9						38	16	3

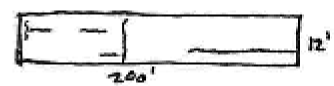
PCI = 97

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH Oktibbeha SECTION 02 SAMPLE UNIT 3

SURVEYED BY JW DATE 6/8/07 SAMPLE AREA $2400\ ft^2$

SKETCH: 400-600



1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

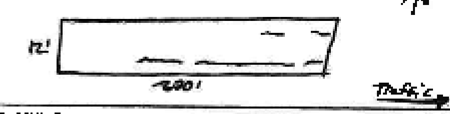
DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
10 L	4	6	7	12	8	6	60			105	4.4	10

PCI=90

ASPHALT SURFACED ROADS AND PARKING LOTS
CONDITION SURVEY DATA SHEET
FOR SAMPLE UNIT

BRANCH [illegible] SECTION 87 SAMPLE UNIT 4
SURVEYED BY JW DATE 6/8/07 SAMPLE AREA 2400 ft²

SKETCH: 600-800



1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

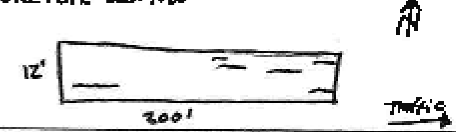
DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
10L	16	5	45	7	7					80	3.3	8

PCI=92

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH Okinawa SECTION 92 SAMPLE UNIT 5
SURVEYED BY JW DATE 6/3/07 SAMPLE AREA 2400 ft2

SKETCH: 800-1400'



1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

DISTRESS SEVERITY	QUANTITY										TOTAL	DENSITY %	DEDUCT VALUE
10L	10	5	11	7	9	9					51	2.1	5

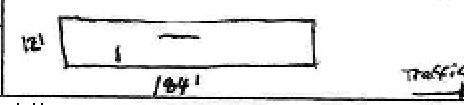
PCI=95

ASPHALT SURFACED ROADS AND PARKING LOTS CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH Okt... SECTION 82 SAMPLE UNIT 6

SURVEYED BY JW DATE 6/3/07 SAMPLE AREA 2200 ft²

SKETCH: 1400 - 1184



1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Bumps and Sags
5. Corrugation
6. Depression
7. Edge Cracking
8. Jt. Reflection Cracking
9. Lane/Shoulder Drop Off
10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering/Raveling

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
10 L	5	10								15	0.7	1.5

PCI=98.5

APPENDIX C

ARKANSAS MAINTENANCE STRATEGY

ARKANSAS STATE HIGHWAY AND TRANSPORTATION DEPARTMENT

July 24, 2002

MAINTENANCE MEMORANDUM NO. 2002-01

TO: District Engineers

SUBJECT: Pavement Edgedrain Maintenance Procedure

The following maintenance procedure should be followed to ensure that pavement edgedrains are open and functioning properly on drainable base pavements:

- Log sections of interstate with edgedrains by log mile and establish a predetermined schedule for inspection and cleaning.
- Spray 3” to 6” around the outlet protectors every year during the growing season with roundup and clean the screens and troughs of the outlet protectors if needed.
- Inspect a minimum of 10% of the edgedrains with video equipment every two years. If problems are found at any location, clean that section and inspect and clean adjacent sections until no other problem exists. The anticipated number of miles requiring cleaning may warrant purchasing a flushing trailer for your district.
- Inspect 100% of the edgedrains with video equipment by contract on the 10^{th} year of service. The contracts are to include flushing as required based on results from video inspection.

This procedure should be implemented this summer on all completed work.

An Underdrain Inspection Report form will be E-mailed to each district for your use. Attached is a sample form.

Leonard Hall
State Maintenance Engineer

cc: Assistant Chief Engineer - Operations