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16. ABSTRACT

This study provides recommendations for using the Road Rater Model 400B and the PEDMOD (Pavement Evaluation and Design Model) program for pavement evaluation and design. In order to address seasonal variation in pavement response for pavement evaluation and design, thirty-six test sections were established in eight counties in Washington State. Road Rater deflection data was collected monthly on the test sections for a period of one year.

The pavement evaluation and design capabilities in the PEDMOD program utilize resilient material properties obtained from WESDEF, a backcalculation analysis program developed at the U.S. Army Corps of Engineers Waterways Experiment Station, which is contained within the PEDMOD program. Results obtained from WESDEF using Road Rater deflection data collected on the test sections indicate that it is difficult to obtain meaningful resilient material properties for pavement layer materials. Results of the analysis of deflection data for seasonal variability indicate that some general trends in variation in maximum deflection and subgrade resilient modulus occurred during the 12-month testing period, however, the test sections should be maintained for a longer period of time to develop specific seasonal correction factors. Recommendations are provided for calibrating the Road Rater and performing systemwide and design level deflection testing as well as recommendations for the use of PEDMOD. In addition, recommendations are provided for alternative techniques for pavement evaluation using parameters obtained directly from Road Rater deflection basins.

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EXECUTIVE SUMMARY

Ten counties in the state of Washington have acquired or share with other counties a Road Rater Model 400B for the purpose of performing deflection testing on their county roads to improve pavement evaluation, design and project prioritization capabilities. In addition, these counties have acquired the PEDMOD (Pavement Evaluation and Design Model) software for accomplishing pavement evaluation and design using deflection data collected from the Road Rater.

The study addresses a number of topics related to the use of the Road Rater and PEDMOD for pavement evaluation and design. Specifically, the study includes (1) a survey of county practices in Washington State regarding pavement design and evaluation; (2) results of a 12-month deflection data collection effort on 36 test sections on county roads in 8 counties to evaluate seasonal variability and seasonal correction factors for a range of pavement types; (3) review and testing of the PEDMOD program and recommendations for its use by Washington counties; (4) recommendations for methods for pavement evaluation using deflection basin parameters; and (5) recommendations for performance and calibration testing of the Road Rater and for accomplishing pavement deflection testing for systemwide and project level studies.

Results of the survey indicated that the counties are primarily interested in using the Road Rater for systemwide testing although there is also considerable interest in using deflection data from the Road Rater for pavement design on BST (bituminous surface treatment) and AC (asphalt concrete) surfaced roads. Typical pavement sections currently existing in the counties consist of BST pavements from 1 to 4 inches thick and AC pavements 2 to 4 inches thick over base layers up to 12 inches in thickness, although there are exceptions to these ranges.

The deflection data collection effort consisted of collecting deflection data monthly for a period of 12 months on the test sections to evaluate seasonal changes in pavement material properties and seasonal correction factors for deflections. Although some trends in seasonal variation were observed for individual test sections, no specific conclusions could be made regarding seasonal variability of material properties or deflections.

Three modules in the PEDMOD program were evaluated in detail for this study including the NDT data processing and reduction module which includes the WESDEF backcalculation program, the pavement evaluation module, and the pavement design module. The study team was unable to obtain good results from the backcalculation analysis with respect to predicted modulus values and levels of error using the WESDEF program in PEDMOD and deflection data collected on the test sections. As a result, it is recommended that considerable judgment be exercised in interpreting results from backcalculation. Alternative methods for evaluating pavement performance using three deflection basin based parameters, including maximum deflection, area parameter, and subgrade modulus obtained from the deflection at the outermost sensor, are provided. Other recommendations for PEDMOD include using a different fatigue equation for evaluation of remaining fatigue life in the pavement evaluation and pavement design module, and using reference pavement temperatures of 70°F and 77°F west and east of the Cascade Mountain Range, respectively, for pavement design.

Recommendations are provided for accomplishing performance tests, relative calibration of the deflection sensors, approximate calibration of the load cell, and absolute calibration of the deflection sensors and load cell on the Road Rater. Performance test methods and approximate calibration methods generally follow the recommendations provided in the Road Rater manual by the manufacturer, Foundation Mechanics, Inc. The relative calibration procedure generally follows the procedures developed by SHRP (Strategic Highway Research Program) for the FWD (Falling Weight Deflectometer).

Further study of backcalculation using the Road Rater data is recommended to improve predictions of modulus values of the pavement layer materials while achieving acceptable levels of error. It is also recommended that deflection data continue to be collected on the test sections to develop specific seasonal correction factors for deflections and evaluate seasonal variability of materials in the pavement structure.

Specific conclusions and recommendations for the study are as follows:

1. The counties are generally interested in using the Road Rater for pavement evaluation and design primarily on flexible pavements with AC and BST surfaces and aggregate base layers.
2. The results from the backcalculation analyses indicate that it is difficult to obtain meaningful resilient modulus values from these analyses. It is recommended that alternative deflection-based criteria be used to evaluate pavement structural condition until further studies can be concluded on backcalculation of resilient modulus values from Road Rater data.
3. Deflection-based criteria recommended for evaluation of pavement performance include the temperature corrected maximum deflection, the temperature corrected area parameter, and the subgrade resilient modulus obtained directly from the deflection at the outer sensor.
4. No recommendations for seasonal correction factors for base, subbase and subgrade materials could be obtained from the deflection data collected on the test sections during the study. The percent change in subgrade resilient modulus values over the 12-month test period varied from 11 percent to 111 percent, with an average percent change of 37 percent. No trends in variation of subgrade resilient modulus with time of year, pavement structure type, geographic location or climatic conditions were observed for the data analyzed.
5. The equation for estimating remaining fatigue life in PEDMOD should be changed to the equation developed by Finn [5] for fatigue life. The number of ESALs to a fatigue failure using the equation currently in PEDMOD is 39 percent higher than the number of ESALs to failure obtained using the Finn equation.
6. Reference temperature conditions in PEDMOD should be changed from 90°F to 70°F and 77°F for counties west and east of the Cascade Mountain Range, respectively, to reflect year-round average pavement temperature conditions in these locations.
7. WSDOT load equivalency factors or Asphalt Institute load equivalency factors are recommended rather than the load equivalency factors in PEDMOD for estimating design period ESALs on county roads.

8. Routine performance tests, relative calibration of the deflection sensors, and approximate verification of the load cell should be performed on a regular basis to minimize the potential for collecting unreliable deflection data.

9. Systemwide testing of county roads to evaluate pavement performance should be done on roads with a functional classification of collector or higher. Deflection testing should be performed within the first year after construction of a new pavement or overlay. After this time, deflection testing should be performed at 2- to 3-year intervals with the frequency of testing increasing with pavement age.

10. Counties should continue to collect deflection data on seasonal correction factor test sections to evaluate seasonal correction factors that could be applied to deflections and subgrade resilient modulus values. Additional data such as subgrade moisture content, laboratory tests of subgrade soils, and frost depths should also be collected to assist in evaluating seasonal correction factors.

CHAPTER 1

INTRODUCTION

Ten counties in the state of Washington have acquired or share with other counties a Road Rater Model 400B, an NDT (nondestructive testing) device, for the purpose of performing deflection testing on their county road systems to improve pavement evaluation, design and project prioritization capabilities. In addition, these counties have acquired the PEDMOD (Pavement Evaluation and Design Model) software through CRAB (County Road Administration Board) for accomplishing pavement evaluation and design using deflection data collected from the Road Rater.

The Washington State Department of Transportation (WSDOT) and several county representatives identified a number of research objectives to be accomplished as part of a study. The study was designed to improve deflection data collection efforts and provide guidance for performing pavement evaluation and design using deflection data to counties unfamiliar with these activities. These objectives are as follows:

1. Provide recommendations for systematic procedures for data collection, equipment verification, and calibration of the Road Rater.
2. Establish test sections in at least five counties and collect deflection data over a 12-month period for the purpose of evaluating seasonal correction factors.
3. Provide recommendations for material properties and empirically derived constants used in PEDMOD that are representative of Washington State county pavements and conditions.
4. Test the components of PEDMOD recommended for use by the counties to verify that reasonable results are obtained.
5. Develop procedures for the use of the Road Rater and PEDMOD.

GeoEngineers identified six tasks to accomplish the objectives of the study. The tasks are as follows:

1. Obtain background information on Washington State county knowledge and experience with pavement evaluation and design, and use of the Road Rater.
2. Develop procedures for equipment testing, verification, and calibration, and nondestructive pavement deflection testing using the Road Rater Model 400B.
3. Develop seasonal correction factors for deflections and pavement material properties for pavement evaluation and design.
4. Review the PEDMOD program and provide recommendations for portions of PEDMOD suitable for use by the counties.
5. Test the portions of PEDMOD recommended for use by the counties.
6. Prepare procedures manuals for the use of the Road Rater and the use of PEDMOD.

7. Prepare a technical report describing the conduct of the study, the results, conclusions and recommendations.

The technical report is organized as follows:
Chapter 1 - Introduction
Chapter 2 - Summary of Background Information
Chapter 3 - Test Sections for Seasonal Correction Factors
Chapter 4 - Review and Testing of the PEDMOD Program
Chapter 5 - Seasonal Correction Factors
Chapter 6 - Procedures for Performing Pavement Evaluation and Design
Chapter 7 - Procedures for Using the Road Rater
Chapter 8 - Conclusions and Recommendations

Chapters 6 and 7 are written as stand-alone documents describing the procedures for performing pavement evaluation and design and procedures for using the Road Rater.

CHAPTER 2

SUMMARY OF BACKGROUND INFORMATION

INTRODUCTION

A survey questionnaire on topics related to pavement types, materials, environmental conditions, and pavement evaluation and design practices for roadways managed by counties in the state of Washington was sent to representatives in each of the 39 counties. The purpose of the questionnaire was to provide the research team with information on the types of roads built and managed by the counties, as well as information on how the counties are currently performing tasks related to pavement deflection testing, pavement evaluation, and pavement design. The survey included questions on the following topics:

1. Pavement System Information
2. Pavement Materials
3. Environmental Conditions
4. Pavement Analysis and Evaluation
5. Road Rater Experience
6. Traffic
7. New Pavement and Overlay Design
8. Personnel

The following 17 counties responded to the survey: Benton, Chelan, Clark, Columbia, Franklin, Garfield, Grays Harbor, King, Lewis, Mason, Pierce, Snohomish, Spokane, Thurston, Walla Walla, Whatcom, and Yakima. The survey questionnaire and a summary of the responses are included in Appendix A. The most significant information received will be summarized in this chapter.

PAVEMENT SYSTEM INFORMATION

The questions in this section were intended to generate general information about the county, the county road system and preferences for Road Rater use within the county. The total centerline miles of roads managed by the 17 counties responding to the questionnaire is 20,606. This represents an average of 1,212 centerline miles per county, with a minimum mileage of 475 miles and a maximum mileage of 2,963 miles.

Of the 20,606 centerline miles of road, 4,518 miles are surfaced with AC (asphalt concrete), 9,033 miles are surfaced with BST (bituminous surface treatment), 6,440 miles are surfaced with AGS (aggregate surfacing), and 186 miles are surfaced with PCC (portland cement concrete).

Of these surfacing types, the counties responding to the questionnaire indicated that they would prefer to use the Road Rater for pavement evaluation and design for AC and BST surfaced roads.

The typical BST pavement structures consist of 1 to 4 inches of BST over 2 to 12 inches of crushed base, ballast, gravel base or pit run materials over native subgrade materials. Typical AC pavement structures consist of 2 to 4 inches of AC over 4 to 6 inches of crushed base or up to 12 inches of gravel base over native subgrade materials.

PAVEMENT MATERIALS

Each county that responded to the questionnaire provided information on surfacing, base, subbase and subgrade materials encountered in their pavement structures. Surfacing materials include ACP, BST, AGS, and PCC as described previously. Base materials include CSTC (crushed surfacing top course), CSBC (crushed surfacing base course), gravel base, ballast, pit run, or no base. Subbase materials include sandy soils, crushed basalt, poorly graded sand, silty or clayey gravels, glacial till, gravel borrow, and clean gravels.

Subgrade materials identified in the responses include silt, basalt rock, rock, clayey silt, river run gravel, cobbles, silty sand, clayey sand, poorly graded sand, silty gravel, till, gravelly sand, gravelly loam, silty loam, silty gravelly loam, sandy loam, and sandy silt. Resistance R-values were provided for some subgrade materials. These values range from 6 to 60. Resilient modulus values reported for subgrade materials range from 15,000 psi to 30,000 psi. One CBR (California Bearing Ratio) value of 5 was reported for a sandy silt.

ENVIRONMENTAL CONDITIONS

Responses to the questions in this section of the questionnaire provided information on freeze-thaw conditions, moisture conditions, and pavement surface temperature conditions within each county.

Sixteen counties responding indicated that they experience ground freezing and thawing within their counties. One county experiences no freeze-thaw. Six of the counties indicated that ground freezing occurs throughout the county and six counties indicated that ground freezing typically occurs only in a portion of the county, with the amount of area where ground freezing occurs ranging from 4 to 80 percent. Average depths of freezing vary from 3 to 36 inches. These depths are obtained from building codes, published information, design frost depths, experience and test holes.

Several questions pertained to moisture conditions within the counties. The responses generally indicated that moisture conditions are quite varied. The majority of the counties responding indicated that dry climate conditions prevail within their counties. However, overall, the responses indicated that the amount of precipitation is quite variable.

The majority of counties responded that ground water is present within a few feet of the frost penetration depth in at least some areas of the county where ground freezing occurs, creating the potential for frost heaving and thaw weakening. In wet climate areas where no ground freezing occurs, three counties indicated that soil within about 3 feet of the ground surface is saturated at some times during the year.

The final question in this section pertained to maximum pavement surface temperatures occurring within each county. Reported maximum pavement surface temperatures varied from less than 100°F to greater than 140°F.

PAVEMENT ANALYSIS AND EVALUATION

Responses to questions in this section provided information on practices currently used by the counties to evaluate pavement condition. The questions were directed primarily toward the use of the Road Rater to accomplish this task.

Thirteen counties responding to the questionnaire indicated that they have used the Road Rater to evaluate the structural condition of their pavements. One county responded that it has used an FWD (falling weight deflectometer) for this purpose. Seven counties use the maximum deflections from the Road Rater to evaluate structural condition while a total of nine counties use the deflection basins to perform their structural evaluations. Four counties use both maximum deflections and deflection basins for evaluating their pavements.

Seven counties reported doing systemwide deflection testing to evaluate structural condition of the pavement, with the majority of these counties performing systemwide deflection testing annually. The spacing of test locations varies from 0.05 mile to 0.10 mile. Six counties reported performing deflection testing between spring and early fall, two counties perform deflection testing in early spring after the thawing period, one county tests between fall and spring, and two counties test year-round.

Of the counties that use deflection basins and backcalculate pavement layer material properties, analysis units to evaluate material properties are selected by using the county road log, observing surface layer changes, observing changes in deflection basins, using construction information, and evaluating maximum deflections. Pavement layer thicknesses are obtained from construction documents, cores, or both. Seed moduli and upper and lower bounds for material properties used in backcalculation are selected from default values in PEDMOD, experience, AASHTO design guides, WSDOT data, coring information, and trial and error.

The counties were asked whether adjustments are made to the deflection data prior to performing any analyses when testing at different times of the year. Four counties indicated that adjustments are made to the deflection data prior to accomplishing any analyses and five counties indicated that no adjustments are made prior to accomplishing any analyses. Of the four counties that make adjustments, three counties make temperature adjustments and four counties make seasonal adjustments.

ROAD RATER EXPERIENCE

This portion of the questionnaire was intended to provide information on county Road Rater operating experience. The questions covered Road Rater ownership, deflection testing practices and calibration.

Six counties in the state of Washington responding to the questionnaire own Road Raters. In addition, four counties in the BFRC (Benton-Franklin Regional Council) co-own a Road Rater. The time of ownership ranges from less than one year to six years. In addition to the counties that own Road Raters, six counties have Road Rater deflection testing performed on their roads by other counties. Two additional counties are planning to purchase a Road Rater, and two additional counties are planning to have testing performed in their county by another county agency.

Nine counties perform deflection testing at 0.1-mile intervals. One county performs deflection testing at 0.05-mile intervals and one county performs deflection testing at 50-foot intervals when doing testing for design. Typically, the target force for deflection testing is 1.2 to 1.3 kips with the load being applied once at each test location unless the resulting deflection basin is questionable. One county reported performing multiple load applications routinely at each test location. Nine counties reported obtaining pavement surface temperatures at every test location and one county obtains pavement temperatures twice a day during testing.

Three counties responded that they routinely calibrate the velocity transducers and the load cell on their Road Rater in general accordance with the recommendations in the Road Rater owner's manual.

TRAFFIC

The information collected in this section of the questionnaire included practices for obtaining traffic information for pavement evaluation and design. Specifically, the questions pertained to sources of traffic data and methods for making traffic projections.

Fourteen counties responded that they obtain traffic information by performing some sort of traffic counts. Two of the fourteen counties indicated that they routinely perform traffic counts and vehicle classifications and three counties indicated that they occasionally perform vehicle classifications. Eight counties reported that traffic counts are performed both systemwide and for new pavement and overlay designs for specific projects. Two counties indicated that traffic counts are obtained systemwide only and four counties indicated that traffic counts are obtained for design projects only.

Six counties reported that mechanical counters are routinely used to get traffic counts. Three counties reported performing some manual counts. The counts were reported to take place over periods of 4 to 7 days.

Other methods or information used to evaluate or project traffic for pavement evaluation and design activities include information from transportation origin-destination studies, growth projections, proposed development information, business-employment information, consideration of industry centers, observations of seasonal changes in traffic volumes or patterns, and information provided in the Asphalt Institute publication MS-17 [1].

Traffic growth and truck growth factors are selected by six counties based on historical traffic count data, by three counties by planning and transportation department recommendations, and by two counties based on WSDOT traffic and truck growth factors. Other bases reported include the Asphalt Institute publication MS-17 and the Federal Administration Highway Capacity Manual [2].

Nine counties reported that ESALs (equivalent single axle loads) are calculated utilizing ESAL factors in the Asphalt Institute publications MS-1 [3] and MS-17 [1]. Six counties reported using ESAL factors for different vehicle classifications from AASHTO. Three counties use ESAL factors from PEDMOD, and one county reported using ESAL factors from WSDOT.

NEW PAVEMENT AND OVERLAY DESIGN

Responses to questions in this section provided information on new pavement and overlay design practices currently used by counties in the state of Washington.

New pavement design is accomplished using the methods provided in PEDMOD by five counties. Four counties use the AASHTO design guide [4] for the design of new pavements and four counties use WSDOT design procedures. Three counties reported using methods outlined in Asphalt Institute publications MS-1 [3] and MS-17 [1]. Two counties use county standards for new pavement design and one county uses WSDOT standard pavement sections.

Ten counties obtain material properties required for new pavement and overlay designs from material testing performed by the WSDOT Materials Laboratory. Three counties obtain material properties from deflection data from the Road Rater. Two counties obtain material properties by classifying soils using the AASHTO soil classification system and correlating material properties with classifications, and one county reported using a visual identification system and correlation procedure. One county reported accomplishing coring and deflection testing using an FWD to obtain pavement material properties, and two counties reported using County Soil Survey information and Soil Conservation Service information to obtain material properties.

The counties were questioned regarding how they obtain layer thickness information for overlay designs. Eight counties responded that they obtain cores to determine pavement layer thicknesses. Four counties responded that they use construction plans to determine layer thicknesses. One county indicated that it uses overlay history and one county said that layer thickness information is based on experience.

One question in this section pertained to checking new pavement or overlay designs with other design methods. Four counties indicated that they routinely check designs with other design methods, six counties said they sometimes check designs with other design methods, and four counties said that they never check designs with other methods.

PERSONNEL

The final section of the questionnaire included questions pertaining to the type of personnel dedicated to pavement testing, analysis, design and management and the amount of time devoted to these activities.

The number of individuals involved in pavement testing, analysis, design and management varied from zero to more than ten individuals for counties responding to the questionnaire. This represents from 0 to 12,000 person-hours per year dedicated to these activities, with the majority of counties devoting between 0 and 1,000 hours per year.

Educational background of the individuals involved in these activities ranges from high school students working part time to individuals with PhDs. Thirteen of the fifteen counties indicated that the individuals who participate in the pavement activities listed above are also responsible for other county engineering activities besides pavement-related activities.

CONCLUSIONS

The information obtained from the questionnaires was used to evaluate typical pavement materials and structures and environmental conditions within the study area. In addition, it provided information on current practices for Road Rater use, pavement evaluation and design procedures, and the amount of time available to perform these activities.

CHAPTER 3

TEST SECTIONS FOR SEASONAL CORRECTION FACTORS

INTRODUCTION

One of the objectives of the study identified by county representatives was the development of seasonal correction factors. Seasonal correction factors may be used to directly adjust deflections that vary seasonally as a result of temperature and moisture conditions. Alternatively, backcalculated material properties may be seasonally adjusted.

Seasonal correction factors were evaluated for this study by establishing test sections on in-use pavements in eight counties in the state of Washington. Deflection data were collected monthly on these test sections for a period of 12 months, and the data were analyzed to evaluate seasonal variability. The selection of test sections, procedures for collecting deflection data, and a summary of the test sections are presented in this chapter.

SELECTION CRITERIA FOR TEST SECTIONS

Eight counties established and maintained seasonal correction factor test sections for a period of 12 months for this study. The counties are Clark, Franklin, Pierce, Snohomish, Spokane, Walla Walla, Whatcom, and Yakima. Each test section was 500 feet in length and 10 fixed test points were located on each test section where deflections were obtained.

Several criteria were established for selecting test sections for evaluating seasonal correction factors. The criteria are as follows:

1. Pavement layer thickness should be known at the beginning of the 12-month data collection period. Alternatively, the counties should have the ability to obtain pavement layer thickness information within the first 4 months of the data collection effort.
2. Pavement layer materials should be known.
3. The pavement surface condition should be good to excellent.
4. Consistent subgrade soil conditions should be present throughout the length of the test section.
5. Reliable traffic estimates should be available for the test sections.

In addition, it was recommended that BST pavements be 1 to 4 inches and AC pavements be 2 to 4 inches in thickness, with base layers up to 12 inches in thickness. These thickness recommendations were based on background information on pavement structures obtained from the survey questionnaire described in Chapter 2. The counties were also requested to select test sections that had a range of subgrade materials types including granular and fine-grained soils representative of subgrade types found within their county.

SITE VISITS

GeoEngineers visited each county in July 1992 to finalize the selection of the test sections for evaluating seasonal correction factors. At each potential test section location, roadway configuration, drainage, topographic relief and pavement surface condition were observed, and the specific 500-foot-long test section location was selected.

DEFLECTION TESTING

Deflection testing was performed at 10 test points spaced 50 feet apart on each test section. Sufficient markings were provided on the pavement to align the vehicle, loading pads, and deflection sensors of the Road Rater at the same location each time testing was performed. The test points were located in approximately the center of the travel lane with the exception of Spokane County where test points were located in the outer wheelpath. The center of the lane was selected to minimize load-related effects on the deflection values obtained. Three tests were performed at each test point location at a target force of 1.2 kips and a target frequency of 25 Hz (hertz). Because of some minor equipment differences, Clark County performed deflection tests at a target force of 1.3 kips.

TEST SECTIONS

Thirty-six test sections were established in the eight counties that participated in the seasonal correction factor portion of the study. The roadways on which the test sections were located and the test section pavement structures are given in Table B1 in Appendix B. Pavement surfacing materials included AC and BST. The surfacing thicknesses ranged from 1 to 8.4 inches of BST, AC or a combined section of BST and AC. Base materials included crushed surfacing, ballast, gravel base, and pit run sand and gravel from 0 to 22 inches in thickness.

Because of various reasons, a number of counties were unable to conduct deflection tests over the entire 12-month period. Table B2 in Appendix B shows the months for which deflection data were collected on each test section and submitted to GeoEngineers for evaluation.

CHAPTER 4

REVIEW AND TESTING OF THE PEDMOD PROGRAM

INTRODUCTION

The PEDMOD software was obtained by CRAB for use by the counties to perform pavement evaluation and design functions using deflection data collected with the Road Rater. The software was developed by Roy McQueen and Associates. The software consists of the following:

1. NDT Data Processing and Reduction Module
2. Pavement Evaluation Module
3. Pavement Design Module
4. Life Cycle Cost Module
5. Reports Module

One of the objectives of the study was to review the modules in the PEDMOD software to evaluate the applicability of the software to pavement types, pavement materials, and environmental conditions in the state of Washington. The results of this portion of the study are described in this chapter.

It was beyond the scope of this study to evaluate the Life Cycle Cost module in PEDMOD. Evaluating life cycle costs for alternative maintenance, rehabilitation and reconstruction options for a facility is an important part of the pavement management process. However, the information from which costs were developed for the Life Cycle Cost module in PEDMOD were obtained from pavements in Virginia. Pavement materials, subgrade conditions, maintenance procedures, preferred pavement types and environmental conditions may vary considerably between Washington and Virginia and, therefore, the results may not be applicable to this location. Therefore, it is recommended that counties using the Life Cycle Cost module do so with caution.

The information obtained from the survey questionnaire indicated that the counties are interested in using the Road Rater and PEDMOD to evaluate flexible pavement structures with AC and BST surfaces and base layers consisting of aggregate materials. The pavement evaluation options and new pavement and overlay design procedures in PEDMOD include methods for performing evaluation and design for both flexible and rigid pavement structures with either stabilized or unstabilized base materials. Based on the information obtained from the survey questionnaire, only the portions of the Pavement Evaluation and Pavement Design modules developed for flexible pavements with aggregate bases were evaluated for this study.

NDT DATA PROCESSING AND REDUCTION MODULE

The NDT data processing component of the module allows the user to import deflection data files from the Road Rater into the LOTUS 1-2-3 spreadsheet environment to perform preliminary analyses of the deflection data. Users must have the LOTUS spreadsheet program installed on their computer to utilize this portion of the PEDMOD program.

The data is transferred into the LOTUS program and a stiffness computation is performed. The stiffness is computed as follows:

$$K = F/D_0 \tag{1}$$

where:

K = stiffness, in pounds per inch x 10^{-3}

F = applied force, in pounds

D_0 = the maximum deflection, in mils (inches x 10^{-3})

Once the data are imported into LOTUS 1-2-3 the user may perform any subsequent analyses or generate graphs of selected data. The purpose of using the data processing component is to review trends in the deflection data, analyze the trends, and select representative deflection basins for backcalculation.

The second component of the data processing and reduction module is WESDEF. WESDEF is a linear layered elastic pavement analysis program developed by the U.S. Army Corps of Engineers at WES (Waterways Experiment Station) in Vicksburg, Mississippi. The WESDEF program backcalculates pavement layer elastic or resilient modulus values using deflection basins from a nondestructive deflection testing device.

The resilient modulus values are obtained by starting the analysis process with seed, or beginning, modulus values. Using the seed modulus values, a deflection basin is obtained from the program for the applied loads and pavement structure specified by the user. The calculated deflections obtained from the analysis are compared to the measured deflections input by the user. If the absolute sum of the difference between the measured and calculated deflections is less than 10 percent, the program is terminated. If the absolute sum of the difference is greater than 10 percent, an optimization routine is called up in WESDEF, new resilient modulus values are selected and the analysis is performed again. Up to three iterations are performed to obtain the best comparison (least difference) between the measured and calculated deflections.

The following information is required to obtain pavement layer resilient modulus values using WESDEF:

1. Deflection data from a nondestructive deflection testing device;
2. Load information including the magnitude of the load and the loading configuration;
3. Pavement layer thicknesses;

4. Beginning, or seed, resilient modulus values for each pavement layer material type to begin the analysis;
5. Ranges of the modulus values for each layer in the pavement structure.

WESDEF includes seed moduli and ranges for modulus values for a number of material types that may be used as default values when backcalculating material properties.

Both the NDT data processing section (LOTUS 1-2-3) and the NDT data reduction section (WESDEF) may be accessed from within PEDMOD or outside of the PEDMOD program. The pavement layer resilient modulus values obtained from the analyses performed in WESDEF may be used in subsequent components of PEDMOD to accomplish pavement evaluation and design functions.

The NDT data processing and data reduction module were tested using Road Rater data collected on the seasonal correction factor test sections described in Chapter 3. The data processing module functioned as anticipated for Road Rater data. Road Raters used by the counties include five deflection sensors. Therefore, the WA5R123.WK1 worksheet is used to import the deflection data into the LOTUS 1-2-3 spreadsheet environment and parse the data. Following the instructions provided in the PEDMOD manual, the data are parsed into columns and the stiffness factor, *K*, is calculated.

The NDT data reduction module (WESDEF) was tested using pavement structure information and deflection data obtained from the seasonal correction factor test sections in Clark, Franklin, Spokane, Yakima and Walla Walla counties for the months of August through December. The default seed moduli and modulus value ranges given in WESDEF were used for the analyses. The depth to bedrock or a firm foundation was assumed to be 240 inches (20 feet) for all cases analyzed.

A summary of the backcalculation results is shown in Appendix C. As described in a previous paragraph, when a backcalculation analysis is performed, the WESDEF program continues to iterate to a "better" solution until the error or difference between the calculated and measured deflection basin is less than 10 percent. This level of error was achieved in only a very few cases analyzed. Therefore, the level of tolerable error for this study was increased to 15 percent. The summary tables for the backcalculation results in Appendix C show the cases where the difference between the measured deflection basin and the calculated deflection basin was less than 15 percent. The results by county indicate that an error of less than 15 percent was achieved in less than 1 percent of the tests analyzed in one county, to up to 53 percent of the tests in another county.

The error between the measured deflections and calculated deflection could be further reduced in some cases to within acceptable levels, i.e., 10 percent, when the upper and lower bounds for the modulus values for the asphalt concrete and unbound base materials were expanded. Although the error was reduced when the limits for the modulus values were expanded, the resulting modulus values obtained from the backcalculation analyses were typically unrealistically high compared to laboratory test results and published values for resilient moduli for these materials.

Backcalculation analyses can result in poor comparisons of measured and calculated deflections for a variety of reasons, including the following:

1. Inaccurate pavement layer thickness information,
2. Inability to identify the presence of a rigid boundary within 20 feet of the ground surface,
3. Errors in measurements of the applied loads,
4. Errors in measurements of the deflections,
5. Limitations of the elastic analyses methods to analyze pavements with thin surfacing layers, and
6. Limitations of using linear elastic analyses to analyze pavement response of nonlinear materials.

Further evaluation of WESDEF was performed by varying the pavement structure information used in the WESDEF analysis to determine if better results could be obtained. Two types of variations of pavement structure information were evaluated. The first type of variation studied included changing pavement structure information on a test section where poor results were obtained from the backcalculation analyses. Several changes were made to the pavement structure information in an effort to see if any of these changes would result in improved results from the backcalculation analyses.

The test section used for this evaluation was Spokane County Test Section 3. The pavement structure for this test section consists of 4 inches of asphalt concrete over 8 inches of base. The initial backcalculation analysis using the deflection data from each test point in this test section for the month of October resulted in an average percent difference in error of 58 percent. In an effort to improve the backcalculation results, the following variations to the pavement structure were evaluated in subsequent backcalculation analyses.

1. Adjusting the rigid boundary to 11 feet, 41 feet, and a semi-infinite distance from the pavement surface. These cases were evaluated since bedrock locations in Spokane County are quite variable and were not known at the site.
2. Increasing the thickness of the asphalt concrete layer by 1 inch and 2 inches. This case was evaluated since initial estimates of the base resilient modulus defaulted to the upper limit of 150,000 psi for that layer.
3. Fixing the resilient modulus of the base course at 25,000 psi. This case was evaluated since base resilient modulus values can be the most difficult layer resilient properties to obtain.
4. Fixing the resilient modulus of the asphalt concrete layer based on the pavement temperature. A value of 875,000 psi was selected for the analysis based on the pavement surface temperature at the time of testing.

5. Combining the surface and base layers for the analysis. This variation was studied since it is sometimes difficult to obtain reasonable results for surface layer resilient modulus values from backcalculation for relatively thin county road type pavements.

The results of these analyses are presented in Table C16 in Appendix C. Some reductions in error were obtained for some of the variations analyzed. The best comparisons between measured and calculated deflections were obtained for the semi-infinite rigid boundary and combined AC and base layer, followed by the rigid boundary at 41 feet and the fixed AC resilient modulus. The results obtained for the rigid boundary raised to 11 feet and a fixed base layer resilient modulus resulted in considerably poorer results compared to the original case analyzed. None of the variations in pavement structure information evaluated improved the results such that realistic resilient modulus values were obtained and the error was reduced to within acceptable levels.

The second type of variation studied included evaluating slight variations in applied loads, measured deflections, and pavement layer thicknesses that may be expected to occur under normal operating conditions with the Road Rater on typical pavements. The two test sections used for these analyses included test sections for which better than average results with respect to estimated layer resilient modulus values and levels of error were obtained from the original backcalculation analyses. The test sections used were Yakima County Test Sections 1 and 3. The pavement structure in Test Section 1 consists of 3.6 inches of asphalt concrete and 12 inches of base. The Test Section 3 pavement structure consists of 4 inches of BST and 8 inches of base. The following variations in load, deflection and pavement thickness were evaluated:

1. Plus and minus 5 percent error in the actual applied load compared to the measured load;
2. Plus and minus 2 percent error in the actual maximum deflection compared to the measured deflection;
3. Plus and minus 1/2 inch difference in the pavement thickness.

The results of these analyses were very interesting. The average percent difference in error for the entire test section varied by only a few percent for all of the cases analyzed. Further, the error at each test point showed little variation for all of the cases analyzed. However, the predicted asphalt concrete layer resilient modulus values at some test locations varied by several times the value obtained for the original case analyzed.

The testing performed for this study does not constitute a thorough evaluation of backcalculating pavement layer material properties using Road Rater deflection data and the WESDEF backcalculation analysis program. However, the results from limited backcalculation analyses performed for this study described in this chapter suggest that acceptable levels of error and/or reasonable results for resilient modulus values were not obtained for the data analyzed.

It is beyond the scope of this study to perform an in-depth evaluation of backcalculation procedures using Road Rater data. There are several possible explanations why the backcalculation analyses performed for this study did not yield usable results. Some possible explanations include:

1. The mathematical equations within the WESDEF program may not be sensitive to the range of deflections measured with the Road Rater using a 1,200 pound load.
2. The inability of the WESDEF program to evaluate the depth to firm foundation.
3. Errors in some of the deflection data due to lack of calibration of deflection sensors or the load cell during the testing period.
4. Errors in pavement structure information on some of the test sections used for backcalculation analyses.

It may be possible to improve the results obtained from backcalculation analyses using Road Rater deflection data using some of the following methods:

1. Performing periodic performance testing and calibration of the deflection sensors and load cell to obtain reliable deflection data.
2. Performing deflection testing at higher load levels.
3. Utilizing other backcalculation analysis programs that allow the deflection data from the Road Rater to be entered directly into the backcalculation analysis program. This will allow the user to efficiently backcalculate material properties for several alternative assumptions regarding pavement structure conditions.
4. Utilizing backcalculation analysis methods that include the ability to estimate the depth to firm foundation.

It is the opinion of the study team that material properties obtained using the current version of WESDEF in the PEDMOD program will be of limited use to the counties. It is anticipated that for those counties that choose to continue to perform backcalculation using WESDEF, considerable judgment will be required in interpreting and using the results.

The methods for performing pavement evaluation and design in the PEDMOD program all require pavement layer resilient modulus values in order to perform the analyses. Generally, these material properties are obtained from backcalculation analyses using WESDEF in the NDT Data Reduction section. Since the results from testing WESDEF with the Road Rater data did not provide reasonable resilient modulus values or acceptable levels of error for most deflection basins analyzed, it is recommended that backcalculation continue to be studied, and at this time, other methods for performing pavement evaluation and obtaining material properties for new pavement and overlay design be considered. Alternative methods that do not require the use of material properties obtained from backcalculation analyses are presented in Chapter 6.

Information obtained from the survey questionnaire reported in Chapter 2 indicated that numerous counties are currently using WESDEF to obtain material properties to perform pavement evaluation and design. Although it is not the recommendation of the study team that WESDEF be used to backcalculate pavement layer material properties, some counties have used WESDEF and will continue to use WESDEF for this purpose.

Where backcalculation will continue to be performed, the layer resilient modulus values obtained from the backcalculation analysis should be compared to laboratory resilient properties or published information on resilient modulus values to determine if the results obtained are reasonable and representative of the material being evaluated.

PAVEMENT EVALUATION MODULE

Several options are available within PEDMOD to evaluate pavement performance. These options are as follows:

1. Estimation of expected life;
2. Estimation of load limitation;
3. Estimation of effective structural number.

PEDMOD also has the ability to convert data on mixed traffic to 18-kip ESALs (equivalent single axle loads) for a variety of vehicle types.

Expected Life

The expected life evaluation method allows the user to estimate the number of load repetitions that a specified pavement structure can sustain until a pavement failure occurs. Generally, an 18-kip ESAL is used for the loading conditions. Two types of failure can be evaluated including fatigue and rutting failures. A fatigue failure occurs when cracks develop in the asphalt concrete surfacing layer. The onset of fatigue failure is a function of the maximum tensile strain in the asphalt concrete layer and the resilient modulus of the asphalt mix. Rutting is a permanent depression in the wheelpaths that can occur as a result of permanent deformation of any of the pavement layers.

The failure criterion specified in PEDMOD for a fatigue failure is taken from the Asphalt Institute MS-1 [3] publication and is as follows:

$$\log N_f = 16.086 - 3.291 \times \log (\epsilon_t / 10^{-6}) - 0.854 \times \log (M_R / 10^3) \tag{2}$$

where:

N_f = the number of 18-kip equivalent single axle loads to failure

ϵ_t = the tensile strain at the bottom of the asphalt concrete layer, in 10^{-6} in/in

M_R = the resilient modulus of the asphalt layer, in psi (pounds per square inch)

This equation was obtained from laboratory fatigue tests and adjusted to represent a condition where fatigue cracking occurred in 20 percent or more of the total pavement area in the AASHTO Road Test.

A more commonly applied failure criterion for fatigue by Finn et al. [5] is as follows:

$$\log N_f = 15.947 - 3.291 \times \log (\epsilon_t /10^{-6}) - 0.854 \times \log (M_R /10^3) \tag{3}$$

This equation represents a fatigue failure which is defined as fatigue cracking occurring in 10 percent of the wheelpath areas. Table 1 shows the number of 18-kip ESALs until failure that would be predicted by each of these equations for a modulus of the asphalt concrete layer of 400,000 psi for a range of maximum asphalt tensile strains. The results indicate that the number of equivalent axle loads to failure for Equation 2 is about 39 percent higher than the number predicted by Equation 3. Studies conducted in the state of Washington indicate that remaining life predicted by Equation 3 may be unconservative particularly for thick pavements, which would result in Equation 2 being even more unconservative.

Based on these findings, the study team recommended that the fatigue failure criterion given in Equation 3 be used in PEDMOD rather than the fatigue failure criterion from Equation 2 that is currently used.

The failure criterion used for rutting is the Chevron rutting criterion also given in the Asphalt Institute publication RR-82-2 [6]. The rutting failure criteria is as follows:

$$N_f = 1.077 \times 10^{18} \times (1/\epsilon_v)^{4.477} \tag{4}$$

where:

N_f = the number of equivalent axle load repetitions to rutting failure

ϵ_v = the maximum vertical subgrade strain at the top of the subgrade layer, in 10^{-6} in/in

The Chevron rutting criterion is a relatively conservative rutting failure criterion compared with other commonly applied rutting failure criterion including Shell [7] and the failure criterion by Brown et al. [8]. The rutting failure criterion in PEDMOD is suitable for pavement evaluation for county roads.

In order to obtain the strain values required for pavement evaluation using the failure criteria in PEDMOD, a layered and elastic analysis is performed for a given pavement structure for an 18-kip ESAL. When the analysis is performed the number of load repetitions to failure are obtained for both failure criteria. The limiting failure criterion will be the failure criterion for which the least number of load repetitions will be sustained before failure occurs.

Expected life calculations can be performed for six different pavement types in PEDMOD. Based on the information provided in the survey questionnaire, only asphalt concrete pavements with aggregate base layers were evaluated. The information required to obtain estimates of expected pavement life within PEDMOD include the following:

1. Elastic properties of the pavement layer materials including the elastic or resilient modulus, M_R, and Poisson's ratio, ν;
2. Pavement layer thicknesses;
3. The magnitude and configuration of the equivalent single axle load.

Generally, pavement resilient modulus values needed to estimate remaining life in PEDMOD are obtained from WESDEF in the data reduction module. Therefore, counties that plan to continue to perform backcalculations will be able to use the remaining life calculation option in the pavement evaluation module at this time.

Pavement layer resilient modulus values obtained from WESDEF are apparent resilient modulus values at the time of testing. Surface layer resilient modulus values are representative of temperature conditions in the pavement surface layer at the time of testing. Likewise, the pavement subgrade and to some extent the pavement base material resilient modulus values obtained from WESDEF represent moisture conditions at the time of testing. When performing the remaining life analysis, pavement layer resilient modulus values should represent some reference temperature condition for the surface layer, and reference moisture conditions for the base and subgrade layers. This may require that resilient modulus values from WESDEF be adjusted to represent reference conditions depending on when the deflection testing is performed.

The 1986 AASHTO Guide for the Design of Pavement Structures outlines a procedure for obtaining average pavement temperatures at the time of testing. The pavement surface temperature measured by temperature sensor on the Road Rater and the average air temperature for five days prior to pavement testing are used to calculate average pavement temperatures. Once the average pavement temperature has been obtained, the resilient modulus of the surface layer can be adjusted to the reference temperature condition. The procedures for estimating average pavement temperature are presented in Chapter 6.

Appendix A of the PEDMOD User's Guide gives resilient modulus adjustment factors for four reference surface layer temperatures including 68°F, 70°F, 90°F, and 100°F. The remaining life section of PEDMOD prompts the user to use a resilient modulus for the surface layer adjusted to a reference temperature of 90°F to obtain the remaining life estimates. Average pavement temperatures on the test sections based on the pavement temperatures obtained on the days that deflection data were collected are shown in Table 2. Although the data are limited and no temperature data were available for months when no deflection data were collected, the results indicate that pavement temperatures of 70°F are more representative of average annual pavement temperature conditions.

Variations in pavement base and subgrade resilient modulus values will also occur annually as a result of changes in moisture conditions in the unbound materials. Generally, the changes will be most pronounced in the subgrade materials. However, where unprocessed materials are used in the base layer or ground water is relatively close to the pavement surface, changes in the modulus of the base layer can also be significant. Because of these variations, reference conditions for resilient modulus or stiffness values should be selected for the base and subgrade layer when performing estimates of remaining life. Variations in subgrade modulus values obtained from the test sections are presented in Chapter 5.

Table 3 presents remaining life estimates obtained for pavements with three different surface layer thicknesses and two different subgrade resilient modulus cases using the PEDMOD failure criteria. The remaining life was estimated using reference pavement temperatures of 50°F, 70°F and 90°F, which resulted in surface layer resilient modulus values of 1,270 ksi, 560 ksi and 190 ksi for these temperatures, respectively. For all cases analyzed, the critical criterion, that is, the criterion which resulted in failure for the least number of load repetitions was rutting. The differences in number of load repetitions to failure for the two criteria were greatest for the 2-inch-thick pavements and least for the 6-inch-thick pavements. As expected, the number of load repetitions to failure is reduced for both criteria as the surface temperatures increase and the surface layer resilient modulus is reduced. As mentioned previously, the failure criterion for fatigue in PEDMOD is less conservative than the failure criterion for rutting. Therefore, it is not too surprising that rutting dominates as the failure criteria. If the failure criteria for fatigue by Finn et al. [5] were used instead of the current fatigue failure criteria in PEDMOD, one would likely see fatigue being the critical criterion for thicker pavement structures (that is, thicker surface layers).

The standard 18-kip equivalent single axle load can be modeled using different tire configurations, that is, single tires or dual tires, and different tire pressures. Load information required for remaining life estimates in PEDMOD includes the number of loaded areas, the tire load, and the radius of the loaded area. The default load in the remaining life section is a set of dual tires inflated to approximately 100 psi. Table 4 shows the relationship between tire pressure and radius for a single tire load of 9,000 pounds and dual tires with a load of 4,500 pounds on each tire. Studies by Mahoney et al. for WSDOT [9] indicate that the majority of tires currently in use on heavy vehicles are dual tires; however, the use of "super singles" is gaining popularity. Generally, single tires are slightly more damaging than dual tire configurations. Performing the remaining life estimates using either a single tire or dual tires at tire inflation pressures of 100 psi is acceptable. Once the user selects a loading configuration for remaining life analyses, it should be used consistently throughout all analyses performed for comparing the performance of roads within the system unless there are particular roads where one or the other tire configuration dominates.

Load Limitation

The load limitation option allows the user to evaluate the maximum load that can be applied to a pavement for a specified number of load repetitions. The information required to use the load limitation evaluation option is the same as the expected life option, including the number of load applications to reach failure.

The load limitation value is obtained in PEDMOD by calculating strains for a specified beginning load level and using the fatigue and rutting failure criteria described in the previous section on expected life. The maximum tensile strain in the asphalt concrete, ϵ_t, and the maximum vertical strain in the subgrade, ϵ_v, are found using the respective failure criterion for these types of failures. The layered elastic subroutine is then used to vary the specified load until strain levels are obtained that result in a failure of the pavement for the specified number of load repetitions.

Effective Structural Number

The Effective Structural Number concept originates from the AASHTO design methods. The Effective Structural Number represents the overall stiffness of the pavement structure. It is calculated as follows:

$$SN = \Sigma\, a_i \times d_i$$

where:

SN	=	the structural number
a_i	=	the layer coefficient of the *i*th layer in the pavement structure above the subgrade
d_i	=	the layer thickness of the *i*th layer in the pavement structure above the subgrade

Layer coefficients for all pavement material types for standard conditions are given in the PEDMOD manual. Layer coefficients are given for standard materials in the surface, base and subbase layers in a pavement structure, and these coefficients are correlated with specific resilient modulus values for those materials. The layer coefficient for a specific pavement layer material is then calculated in PEDMOD according to the recommendations in the 1986 AASHTO Guide [4] as follows:

$$a_{im} = a_{is} \times (E_{im}/E_{is})^{1/3} \tag{6}$$

where:

a_{im}	=	the layer coefficient of the *i*th layer for a specific material type being evaluated in a given pavement structure
a_{is}	=	the layer coefficient of the *i*th layer for the standard material with a specified resilient modulus
E_{im}	=	the resilient modulus of the *i*th layer material type being evaluated
E_{is}	=	the resilient modulus of the *i*th layer of the standard material

When this computation is performed in PEDMOD, the value of a_{im} cannot be greater than the value of a_{is}.

Standard layer coefficients, resilient modulus values and the conditions represented by these values for flexible pavement structure materials included in PEDMOD and evaluated for this study are presented in Table 5. The untreated aggregate base refers to a processed material that has some crushed faces. The select base and subbase material refers to a material with a limited amount of fines for which the only processing may be screening.

Table 5 indicates that the default resilient modulus for asphalt concrete at 68°F is 800,000 psi. Modulus temperature relationships from Asphalt Institute publication MS-1 [3] and WSDOT [10] indicate that asphalt concrete resilient modulus values at this temperature are in the range of 500,000 to 620,000 psi. The use of a standard resilient modulus value of 800,000 psi will result in unnecessarily low values of the layer coefficient, a_{im}, for the asphalt concrete. The user should adjust the standard resilient modulus to 600,000 psi when calculating the structural number.

The layer coefficient recommended in PEDMOD for bituminous surface treatments is 0.17, which corresponds to a resilient modulus value of 135,000 psi. The study team has found that backcalculated resilient modulus values obtained from BST pavements are typically much higher than a value of 135,000 psi and can approach those of asphalt concrete at similar temperatures. For purposes of calculating a structural number in PEDMOD, it is recommended that the layer coefficient of a BST surface layer be obtained by using the asphalt concrete material type with a default resilient modulus, E_{is} of 1,000,000 psi at 68°F. This value does not represent the laboratory resilient modulus of BST at 68°F but will result in reasonable values for the layer coefficient obtained from Equation 6. Values for the layer coefficients will range from about 0.25 to 0.30 which are consistent with the experience of the research team for BST pavements.

Layer coefficients obtained from PEDMOD for unstabilized base and subbase materials are generally adequate for the materials encountered on typical county roads.

18-Kip ESAL Repetition

This section of the Pavement Evaluation module allows the user to convert mixed traffic to 18-kip ESALs to perform pavement evaluation or design functions. When this computation is performed before other pavement evaluation or design functions, the number of ESALs is stored by PEDMOD for use in the evaluation and design computations.

Table 6 gives the load equivalencies for different vehicle types used in PEDMOD to convert mixed traffic to 18-kip ESALs. Table 7 gives load equivalencies used by WSDOT to convert mixed traffic. Tables 8 and 9 present load equivalencies for different vehicle types from national data compiled by the Federal Highway Administration for rural and urban road systems in MS-1 [3]. Comparisons of load equivalencies used in PEDMOD to the WSDOT and Asphalt Institute sources suggest that the load equivalencies in PEDMOD may be low for rural road applications. For example, use of the PEDMOD load equivalencies for semi-tractor trailer trucks compared to the WSDOT load equivalencies would result in an underprediction of 18-kip ESALs by 13.6 percent for that vehicle type. The load equivalencies from WSDOT are comparable to the range of values shown for rural roads in the Asphalt Institute table and are straightforward to use. If more detailed information on truck types are available, the Asphalt Institute load equivalencies may be used.

PAVEMENT DESIGN

Introduction

The pavement design module includes options for design of overlays and new pavement sections. For this study, the overlay and new design methods for AC and BST surfacings over aggregate bases were evaluated.

The design methods in PEDMOD for flexible pavements with unstabilized bases are mechanistic-empirical based design methods. The design proceeds by analyzing a specific pavement to obtain stresses and strains at critical locations in the pavement structure. The strains obtained at critical locations are used to evaluate the number of load repetitions to failure using the failure criteria for fatigue and rutting described in the pavement evaluation section. If the number of load repetitions to failure obtained from this analysis is less than the number of load repetitions specified for the design period, the pavement surface layer thickness is increased until the number of load repetitions in the design period equals the number of load repetitions at failure.

The information required to complete an overlay or new design is as follows:

1. Pavement layer thicknesses;
2. Pavement layer resilient modulus values;
3. Number of load repetitions in the design period;
4. Load configuration;
5. Location of the evaluation points for obtaining strains.

New pavement designs and overlay thicknesses obtained from any design procedure will be sensitive to the input variables including pavement structure information and traffic loading. Layer thicknesses and material properties can be quite variable and are not known with certainty except where coring and laboratory testing have been completed. Depending on the available information concerning the existing type and amount of traffic, and growth projections, the design life traffic may not be known with a great deal of certainty.

Pavement Layer Properties

It is anticipated that pavement structure information for existing pavement structures, that is, layer thicknesses and resilient modulus values, will be available from field verification including deflection testing and coring. The surface layer resilient modulus will be sensitive to the pavement temperature at the time of testing. The unstabilized layer resilient modulus values, particularly the subgrade resilient modulus, will vary as a function of moisture conditions.

PEDMOD uses 90°F as a design reference temperature for the resilient moduli of existing and new surface layers for pavement design. The user is required to enter resilient modulus values for new and existing surfacing layers for a reference temperature of 90°F. For temperature and climate conditions in Washington, design reference temperatures from 70°F to 80°F are more suitable for pavement design. The 90°F reference temperature condition can be overridden by entering a resilient modulus value for a more appropriate reference temperature. If 70°F is the selected design reference temperature, the table in Appendix A of the PEDMOD manual can be used to obtain the resilient modulus of the existing surface layer for 70°F as follows:

$$E_{AC\ 70°F} = F_{e\ 70°F} \times E_{AC\ test\ T} \tag{7}$$

Where:

$E_{AC\ 70°F}$ = the resilient modulus of the surface layer for a reference temperature of 70°F

$F_{e\ 70°F}$ = temperature adjustment factor for a reference temperature of 70°F. The factor is obtained by entering the table at pavement temperature *T*.

$E_{AC\ test\ T}$ = the resilient modulus of the surface layer with an average pavement temperature *T*, at the time of testing

If a design reference temperature other than those given in Appendix A of the PEDMOD manual is selected, the following procedure should be used to obtain the resilient modulus for the reference temperature.

1. Compute the resilient modulus value for the reference temperature and the average pavement temperature at the time of testing using the following modulus temperature relationship from WSDOT [10]:

$$E_{AC} = 10^{[6.47210-0.000147362(T^{4})]} \tag{8}$$

where:

E_{AC}	=	resilient modulus at temperature T, in psi
T	=	average pavement temperature, in °F

2. Find the correction factor as follows:

$$F_e = E_{AC\ ref\ T} / E_{AC\ test\ T} \tag{9}$$

where:

$E_{AC\ ref\ T}$	=	the resilient modulus of the surface layer at the reference temperature
$E_{AC\ test\ T}$	=	the resilient modulus of the surface layer at the test temperature

3. Obtain the reference temperature resilient modulus value for the subject material by multiplying F_e times the modulus value obtained from the backcalculation analysis.

$$E_{AC\ ref\ T} = F_e \times E_{AC\ test\ T} \tag{10}$$

Once a design reference temperature is selected, correction factors for that reference temperature can be calculated using Equation 9.

The structural number, *SN*, is also calculated for new pavements and existing pavements with overlays in the design module. The structural number value will not be correct and should be ignored when the design reference temperature for the surface layer is changed to a value other than 90°F.

Design Loads

The total number of design loads or equivalent single axle loads for the design period are required to perform overlay or new pavement design. Obtaining the number of ESALs for pavement evaluation or design is described in the section on traffic in Chapter 2.

The standard load configuration in the design module is a single 18-kip axle with dual tires. As described previously, this tire configuration is currently found on the majority of vehicles. However, as mentioned previously, the single tires are gaining popularity and represent more damaging conditions.

Example Designs

Overlay Designs. As part of the study, overlay designs were completed for two pavement structures considered to represent typical county road pavement structures and traffic conditions. These designs evaluated the effects of variations in pavement layer resilient modulus values and design life traffic on predicted overlay thicknesses. The reference case pavement structures and traffic conditions are as follows:

County Road 1

Pavement Structure Design Data

Layer	Material Type	Layer Thickness (inches)	Modulus (psi)
Surface	BST @ 70°F	2	200,000
Base	Select Aggregate	9	15,000
Subgrade	-	-	10,000

Traffic Loading Data

Average Daily Traffic	300
Design Life for Overlay	15 years
Growth Rate	3 percent

County Road 2

Pavement Structure Design Data

Layer	Material Type	Layer Thickness (inches)	Modulus (psi)
Surface	AC @ 70°F	4	400,000
Base	Aggregate	9	25,000
Subgrade	-	-	15,000

Traffic Loading Data

Average Daily Traffic	1,000
Design Life for Overlay	15 years
Growth Rate	4 percent

Variations in surface layer resilient modulus values, reference temperature conditions, subgrade modulus values, ADT, and percent traffic growth were evaluated. Table 10 shows the specific variations analyzed and the overlay thicknesses predicted using PEDMOD. Overlay thicknesses predicted for the 2-inch-thick BST pavement ranged from 2.0 to 4.5 inches for the cases evaluated. The design overlay thickness was most sensitive to a variation of ±5,000 psi in the subgrade resilient modulus and least sensitive to a variations of ±2 percent in the traffic growth factor for the cases analyzed. Overlay thicknesses predicted for the 4-inch-thick AC pavement analyzed ranged from 2.5 to 7.0 inches. The thicknesses were most sensitive to variations of ±10°F to the reference temperature of the asphalt concrete resilient modulus and least sensitive to variations of ±5,000 psi in the subgrade resilient modulus.

Other pavement structures and traffic combinations may be sensitive to different variables compared to the 2- and 4-inch pavement structures analyzed. Counties are encouraged to perform similar analyses to evaluate the effects of variations in inputs to the design process since many of these variables may not be known with a great deal of certainty.

The overlay thicknesses obtained for County Road 1 and 2 were compared to overlay thicknesses obtained from two other overlay design procedures. The design procedures include the overlay design procedure in the 1986 AASHTO Guide for the Design of Pavement Structures [4] and the Effective Thickness Design procedure in the Asphalt Institute publication, MS-17 [1]. The results are shown in Table 11. The results indicate the PEDMOD overlay thicknesses were consistently greater than those using the AASHTO design procedures and less than those using the Asphalt Institute design procedures.

New Pavement Design. New pavement designs were completed for two traffic loading cases selected to represent typical county road traffic conditions to compare new pavement designs obtained using PEDMOD with designs obtained using the AASHTO flexible pavement design procedure and the Asphalt Institute pavement design procedure. The design periods and traffic loading conditions selected for this analysis are as follows:

Low-Volume County Road Case

Average Daily Traffic	300
Design Life	15 years
Traffic Growth Rate	3 percent

High-Volume County Road Case

Average Daily Traffic	1,000
Design Life	15 years
Traffic Growth Rate	4 percent

New pavement designs were completed for both a low-volume road case and a high-volume road case using all three design procedures and assumed subgrade resilient modulus values. Subgrade resilient modulus values of 5,000 psi, 10,000 psi, and 15,000 psi were assumed for the low-volume road case and values of 10,000 psi, 15,000 psi, and 20,000 psi were assumed for the high-volume road case. The base layer selected for six of the seven cases analyzed consisted of a crushed base material 9 inches thick with a resilient modulus value of 25,000 psi. A reference temperature condition of 70°F was selected for the asphalt concrete in PEDMOD. This resulted in a resilient modulus value of 560,000 psi using the WSDOT modulus-temperature relationship. One low-volume case was analyzed with the base layer as the design layer and the asphalt concrete surface layer thickness fixed at 4 inches.

For all of the cases analyzed, the minimum surface layer thickness for the new pavement sections was obtained using the AASHTO design procedure, and the maximum surface layer thickness was obtained using the Asphalt Institute design procedure. Surface layer thicknesses obtained using PEDMOD were in between the results obtained using AASHTO and AI; however, the PEDMOD results were generally closer to the thicknesses obtained using the Asphalt Institute design procedure. There was one exception to these results. The pavement surface layer thickness obtained from PEDMOD for the high-volume county road case with a subgrade resilient modulus value of 20,000 psi was 5.1 inches compared to 5.0 inches for the same case using the Asphalt Institute procedure.

The information obtained from the survey questionnaire indicated that many counties check or compare new pavement or overlay designs by computing design sections from two or more design procedures and also by comparing the designs with experience. It is recommended that designs from PEDMOD be checked using one or more alternative design procedures.

CHAPTER 5

SEASONAL CORRECTIONAL FACTORS

INTRODUCTION

At the beginning of the study, it was anticipated that seasonal variations in pavement layer resilient modulus values would be evaluated by backcalculating modulus values from the monthly deflection data collected on the seasonal correction factor test sections. However, as stated previously, the results from the backcalculation analyses did not provide usable modulus values for this purpose. It was the conclusion of the study team that alternative methods for evaluating pavement performance and obtaining pavement layer material properties should be used.

Parameters based directly on deflection data were selected to evaluate pavement response until further investigation into performing backcalculation on deflection data from the Road Rater can be completed. The following parameters were selected:

1. Maximum deflection, D_0.
2. Deflection at the outer sensor, D_4.
3. Area parameter, A.

Maximum deflection was selected as a measure of overall pavement response and stiffness. The deflection at the outer sensor was selected to evaluate subgrade modulus. The area parameter used in combination with maximum deflection is a useful parameter for evaluating which layers in a pavement structure may be weak or distressed. A discussion of the use of each of these parameters, the methods for analyzing the seasonal variation of the selected response parameters, and the results are presented in this chapter.

The results of the analysis of the deflection data from the seasonal correction test sections are very general. This is a result of a number of factors, which are as follows:

1. The data were collected for a period of only one year, which is a very limited time to evaluate the effects of seasonal climatic variations on pavement performance.
2. Many counties encountered difficulties in collecting data during all months in the 12-month test period.
3. Some of the deflection data are of questionable quality because of difficulties with equipment calibration and/or improperly seated sensors.

Sufficient deflection data were collected on 26 of the 36 test sections to evaluate seasonal variation. Seasonal variations of maximum deflections, temperature corrected maximum deflections, subgrade resilient modulus values and temperature corrected area parameters are presented for 21 of the test sections in Figures D1 through D21. No figures are included for the five Whatcom County test sections. For about one-half of the 12-month testing period, difficulties in seating the deflection sensors on the Whatcom County Road Rater were encountered, which resulted in extreme variability in recorded deflections. Some of the data from Whatcom County are presented in tables of results included in Appendix D.

MAXIMUM DEFLECTION (D_0)

The maximum deflection has been used in numerous pavement evaluation and design methods to indicate overall response and stiffness of a pavement structure. Comparisons of maximum deflections measured on pavements with similar functional classifications and traffic loading conditions can be a useful tool in comparing relative performance of these facilities.

The maximum deflection under the center of the loaded area results from the accumulation of strain in the surface, base and subgrade layer. As noted previously, for AC and BST pavements, the resilient modulus of the surface layer, which is a measure of stiffness, varies as a function of temperature. The resilient modulus, or stiffness, of the unstabilized layers varies as a function of moisture conditions in these layers.

The variation of average maximum deflection for each test section over the 12-month test period is shown for each test section in Figures D1 through D21. Table D1 shows the maximum and minimum deflections obtained on each test section for the 12-month data collection period and the months when the minimum and maximum deflections were observed. Minimum D_0 deflections were most frequently observed in early fall, although there were several exceptions to this trend. Minimum D_0 deflections were measured in spring in Franklin County and on test sections WA01 in Walla Walla County and WH04 and WH05 in Whatcom County also in spring. Maximum D_0 deflections were generally observed in late fall and spring. The difference between minimum and maximum D_0 ranged from 17 percent to 173 percent, with an average value of 72 percent over the 12-month study period. Sufficient data were not available to provide correlation of maximum deflection with specific conditions of geographic location, subgrade soil types, ground water levels, pavement structure, and local climatic conditions.

SUBGRADE RESILIENT MODULUS (M_R)

The subgrade resilient modulus can be estimated directly from deflections obtained from the Road Rater measurements using the following equation from elastic theory:

$$M_R = P(1-\nu^2)/(\pi \times D_r \times r) \tag{11}$$

where:

M_R	=	subgrade resilient modulus, in psi
P	=	the applied load, in pounds
ν	=	Poisson's ratio, generally 0.40 for subgrade soils
D_r	=	pavement surface deflection at distance r from the center of the loaded area
r	=	distance from the center of the load to D_r

The location of the sensor used for this calculation must be far enough away from the loaded area so that the deflection is not affected by the base and surfacing layers. This location can be determined using methods outlined in the 1986 AASHTO Guide [4]. The deflection at the outer sensor location, D_4, should be used for this calculation.

The average subgrade resilient modulus was calculated for each month when deflection data were collected during the 12-month test period on each test section. Figures D1 to D21 show the variation of subgrade resilient modulus versus month for 21 test sections. Table D2 presents the minimum and maximum subgrade resilient modulus values obtained on each test section. The subgrade resilient modulus calculated from the outer sensor deflection, D_4, for Pierce County test section 4 was extremely low, varying from 1,850 psi to 2,400 psi over the 12-month test period. Subgrade resilient modulus values on the remaining test sections varied from 9,460 psi to 50,740 psi. The resilient modulus value of 50,740 psi was obtained for a subgrade consisting of fractured basalt at test section 5 in Spokane County. The difference between the minimum and maximum subgrade modulus on the test sections ranged from 11 percent to 111 percent, with an average value of 37 percent. Minimum subgrade resilient modulus values generally occurred in late fall and spring and maximum subgrade resilient modulus values were usually present in summer and early fall, although there were exceptions to these times.

AREA PARAMETER (*A*)

The area parameter is calculated as follows:

$$A = \frac{12}{D_0}\left(\frac{1}{2}D_0 + D_1 + D_2 + \frac{1}{2}D_3\right) \tag{12}$$

where:

A	=	the area parameter, in inches
D_0	=	the maximum deflection, in mils
D_1	=	the deflection at 12 inches from the center of the load, in mils
D_2	=	the deflection at 24 inches from the center of the load, in mils
D_3	=	the deflection at 36 inches from the center of the load, in mils

As the equation suggests, the area parameter is the area under the deflection basin for a distance of 36 inches out from the center of the loaded area normalized with respect to the maximum deflection, D_0. When a pavement structure is "perfectly stiff," the deflections at all of the sensor locations are equal to D_0 and the area parameter equals a value of 36.0. When the pavement is "perfectly flexible," the deflections will behave in a well-defined manner according to elastic theory and the resulting area parameter will be 11.1. Therefore, 36.0 and 11.1 represent upper and lower bounds for the area parameter, respectively. Values at the lower end of this range suggest that the pavement structure is fairly flexible and values at the upper end of this range indicate that the pavement is relatively stiff. When the area parameter is used in conjunction with the maximum deflection and the subgrade resilient modulus, the overall condition of the pavement can be evaluated.

The average area parameter was calculated for each test section for each month that deflection data was collected in the 12-month test period. Table D3 presents the minimum and maximum area parameter values obtained on each test section. Values of the area parameter obtained on the test sections ranged from a low of 11.84 on a light BST pavement in Franklin County (Test Section 3) to maximum value of 28.88 on a stiff pavement in Whatcom County (Test Section 2) with a 7.5 inch asphalt concrete surface layer. Seasonal variations in the area parameter observed on the test sections ranged from 11 percent to 42 percent with an average variation of 20 percent. Sufficient data were not available to show any trends in seasonal variation of the subgrade resilient modulus with pavement structure, subgrade soil type, geographic location or climatic conditions.

SEASONAL CORRECTIONS

Although variations in subgrade support conditions, that is, subgrade resilient modulus values, were observed on the test sections, no consistent trends with respect to season or subgrade type were identified. Therefore, no specific seasonal correction factors were identified that could be applied to maximum deflections or the area parameter resulting from changes in moisture conditions.

The maximum deflections were corrected for temperature using two methods including the method outlined in the 1986 AASHTO Guide for the Design of Pavement Structures and the temperature correction method developed by WSDOT. The methods outlined in AASHTO to make temperature corrections to maximum deflections use 70°F as a reference temperature. The WSDOT temperature correction method uses a reference temperature of 77°F. The results obtained using the AASHTO method generally resulted in high corrected maximum deflections for pavement temperatures below 45°F. This phenomenon was eliminated when the WSDOT temperature correction method was used. The study team found no physical justification for the high maximum deflections that resulted from the AASHTO procedure at low temperatures. Therefore, the WSDOT method was selected to perform temperature corrections on maximum deflections as well as temperature corrections to the area parameter. The results are shown on Figures D1 through D21 and in Tables D2 and D5 for the temperature corrected maximum deflection and area parameter, respectively.

The percent difference between the maximum and minimum temperature corrected maximum deflections ranged from 30 percent to 178 percent, with an average value of 86 percent for the 12-month test period. The minimum temperature corrected deflections occurred from June through October on all test sections with the majority occurring in June, July and August. The maximum temperature corrected deflections typically occurred from December through April. Minimum and maximum temperature corrected maximum deflections were generally obtained at the same time of the year for the test sections in each county.

The percent variation in the temperature corrected area parameter ranged from 4 percent to 65 percent, with an average variation of 25 percent. The minimum temperature corrected area parameter generally occurred from November through March. The maximum temperature corrected area parameter generally occurred from June through September. However, there were exceptions to this, including three test sections where the maximum temperature corrected area parameter occurred in April. Minimum and maximum temperature corrected maximum deflections were generally obtained at the same time of the year for the test sections in most counties.

It is recommended that the counties maintain the seasonal correction factor test sections and continue to collect deflection data in a manner consistent with the methods used for this study. Additional data such as climate data, including temperature and precipitation, subgrade moisture content, laboratory resilient modulus values on relatively undisturbed samples of subgrade, and frost depths should also be collected. This information can be used to assist the counties in identifying seasonal variation of pavement materials and pavement response.

CHAPTER 6

PROCEDURES FOR PERFORMING PAVEMENT EVALUATION AND DESIGN

INTRODUCTION

In general, pavement evaluation and design procedures are using more mechanistic-based methods. Most of the mechanistic-based evaluation and design procedures require that resilient modulus values be known for the pavement layers in order to use the methods. Generally, material resilient modulus values used to evaluate pavement performance and accomplish pavement designs are obtained by backcalculating resilient modulus values from deflection testing data.

It is the recommendation of the study team at this time that pavement performance be evaluated using criteria based directly on measured deflection values. These criteria are as follows:

1. Maximum temperature corrected deflection
2. Subgrade resilient modulus
3. Temperature corrected area parameter

Design procedures typically used by the counties include PEDMOD, AASHTO, and Asphalt Institute. Information on pavement layer resilient properties is required for some or all of the layers in the pavement system to use these design procedures. Recommendations will be provided in this chapter for obtaining appropriate pavement layer resilient properties for these design procedures using methods other than backcalculation.

AVERAGE PAVEMENT TEMPERATURE

Any deflections measured by the Road Rater that are affected by the pavement surface layer must be corrected to a reference temperature to make meaningful comparisons in pavement performance. This includes the maximum deflection and the area parameter for the deflection-based performance criteria recommended for use in this study.

The average pavement temperature is required to make temperature corrections to the maximum deflection and the area parameter. For evaluating pavement performance or completing pavement designs, the average pavement temperature is also required in order to adjust the resilient modulus value of the asphalt concrete obtained during testing to a reference temperature.

The average pavement temperature is obtained using a method developed by Southgate [11] which is outlined in Appendix L of the 1986 AASHTO Guide for the Design of Pavement Structures. The information required to estimate the average pavement temperature is as follows:

1. The pavement surface temperature at the time of testing
2. The mean air temperature for five days prior to testing

3. The thickness of all layers containing asphalt concrete materials or BST

The pavement surface temperature is obtained from the temperature sensor on the Road Rater. The mean air temperature for five days prior to testing is calculated as follows:

$$T_m = (T_{high} + T_{low})/10$$

where:

T_m = the mean air temperature, in °F

T_{high} = the recorded daily high temperature, in °F

T_{low} = the recorded daily low temperature, in °F

The average pavement temperature is obtained by entering the chart shown in Figure 1 with the sum of the pavement surface temperature and the mean five-day air temperature, and the average depth of the asphalt concrete or BST layer. An example of estimating the average pavement temperature is presented in Appendix E.

PAVEMENT EVALUATION

Introduction

Performance criteria based directly on deflection data have been selected to evaluate pavement response since backcalculated material properties are not recommended for use at this time. The performance criteria selected are as follows:

1. Temperature corrected maximum deflections, $D_{0\ TC}$
2. Subgrade resilient modulus, M_R, obtained from D_4 deflections
3. Temperature corrected area parameter, A_{TC}

In the following sections, the use of each of the performance criteria are described and the methods for obtaining the criteria are explained.

Temperature Corrected Maximum Deflection, $D_{0\ TC}$

The temperature corrected maximum deflection is used as an overall measure of pavement response and stiffness. Newly constructed or overlaid pavements will have different maximum deflections depending on the pavement structure and subgrade support conditions. The maximum deflection is generally expected to increase with time as the pavement structure deteriorates over time. This can occur for a number of reasons including aging of the surfacing material, fatigue cracking in the surfacing material, degradation of the base layer, softening of the subgrade as a result of moisture and/or freeze-thaw effects, rutting of one or several layers in the pavement structure, or a combination of these.

It has generally been observed that the rate of deterioration of a pavement increases with time. The same trend is expected with maximum deflection. A history of maximum deflection on a roadway segment over the life of the pavement can be used to develop a deflection-based performance curve for the road to identify when it is approaching the end of its serviceable life.

In order to compare deflections obtained on a road segment over time, the measured deflections should be corrected to a standard or reference temperature and subgrade condition. The study team was not able to identify specific recommendations for corrections for subgrade conditions. Therefore, no corrections to maximum deflections for subgrade conditions are recommended at this time.

Corrections for temperature are recommended to adjust the measured maximum deflection to a reference temperature condition of 77°F using the temperature correction method developed by WSDOT. Temperature corrected maximum deflections are obtained as follows:

1. Normalize the deflection data to a standard load of 1,200 pounds;
2. Perform a temperature correction on the normalized maximum deflection to represent expected pavement deflections at the reference temperature conditions.

The normalized deflections are computed as follows:

$$D_{iN} = D_i \times (P_{standard} / P_{measured}) \qquad (13)$$

where:

D_{iN}	=	the deflection at the ith sensor location normalized to a standard load of 1,200 pounds, in mils
D_i	=	the measured deflection at the ith sensor location, in mils
$P_{standard}$	=	the standard load of 1,200 pounds
$P_{measured}$	=	the load when the test was performed, in pounds

The temperature corrected maximum deflection is found using the following equation:

$$D_{0\,TC} = D_{0\,N} \times (1.598837 - 0.009211683 \times T_{avg\,pav}{}^{.96}) \qquad (14)$$

where:

$D_{0\,TC}$	=	the temperature corrected maximum deflection, in mils
$D_{0\,N}$	=	the normalized maximum deflection, in mils
$T_{avg\,pav}$	=	the average pavement temperature, in °F

Subgrade Resilient Modulus, M_R

The subgrade resilient modulus is used to evaluate subgrade support conditions both for pavement evaluation and design. As shown in Chapter 5, the subgrade resilient modulus can be estimated from the deflection at the outer sensor, D_4, on the Road Rater as follows:

$$M_R = P(1-\nu^2)/(\pi \times D_r \times r) \tag{11}$$

where:

M_R	=	the subgrade resilient modulus, in ksi
P	=	the applied load in pounds
ν	=	Poisson's ratio, generally 0.40 for subgrade soils
D_r	=	the deflection at a distance r from the center of the loaded area
r	=	the distance from the center of the load to D_r

Using a load of 1,200 pounds, a Poisson's ratio of 0.40, and a distance of 48 inches to D_4, the equation is simplified to the following:

$$M_R = 6.6845 / D_{4N}$$

where:

D_{4N}	=	the deflection at a distance of 48 inches from the loaded area normalized to a 1,200 pound load

Temperature Corrected Area Parameter, A_{TC}

The area parameter is the area under the deflection basin for a distance of 36 inches out from the center of the loaded area, normalized with respect to the maximum deflection, D_0. As shown in Chapter 5, the area parameter is calculated as follows:

$$A = \frac{12}{D_0}(1/2\ D_0 + D_1 + D_2 + 1/2\ D_3) \tag{12}$$

where:

A	=	the area parameter, in inches
D_0	=	the deflection at the center of the loaded area, in mils
D_1	=	the deflection at 12 inches from the center of the loaded area, in mils
D_2	=	the deflection at 24 inches from the center of the loaded area, in mils
D_3	=	the deflection at 36 inches from the center of the loaded area, in mils

The area parameter is an indicator of the overall stiffness of the pavement structure. The maximum value of the area parameter for a perfectly stiff pavement is 36.0. The minimum value for a very flexible pavement is 11.1. In general, the area parameter is used along with the maximum deflection and the subgrade resilient modulus to evaluate the overall condition of the pavement.

The area parameter also requires a temperature correction to a reference temperature condition. The temperature correction can be made using the following equation developed by WSDOT:

$$A_{TC} = A \times (.7892321 + .0001259143 \times T_{avg\ pav}{}^{1.71}) \qquad (15)$$

where:

A_{TC}	=	the temperature corrected area parameter, in inches
A	=	the area parameter, in inches
$T_{avg\ pav}$	=	the average pavement temperature at the time of testing, in °F

Interpretation of Results

The temperature corrected maximum deflection is the primary criteria used for evaluating pavement performance. Changes in temperature corrected maximum deflections can be used to observe changes in stiffness and load-carrying capacity for individual analysis units. The subgrade resilient modulus and the temperature corrected area parameter will be useful for further interpretation of changes in the maximum deflection over time and the overall condition of the pavement structure. Some general guidelines for using these deflection-based performance criteria for pavement evaluation are as follows:

Performance Criteria			
Temperature Corrected Maximum Deflection	Temperature Corrected Area Parameter	Subgrade Resilient Modulus	Interpretation
Low	Low	High	Weak pavement structure, strong subgrade
Low	High	High	Strong pavement structure, strong subgrade
High	Low	Low	Weak pavement structure, weak subgrade
High	High	Low	Strong pavement structure, weak subgrade

The performance criteria described herein indicate performance with respect to load-carrying capacity of a pavement. These performance criteria should be used in conjunction with pavement surface condition information to evaluate overall pavement condition and performance.

As stated in Chapter 5 on seasonal correction factors, no recommendations can be made at this time regarding adjustments to maximum deflections, subgrade resilient modulus, or area parameter to account for variations in subgrade support conditions resulting from changes in moisture conditions. When a county is interpreting the results obtained for temperature corrected maximum deflections and area parameters, and subgrade resilient moduli some consideration should be given to moisture conditions that may be present in the subgrade soils due to prolonged periods of precipitation, spring thawing, irrigation, or other factors that may affect the results. It is recommended that the counties continue to monitor seasonal correction factor test sections to collect more data on seasonal variation of deflections and deflection-based performance criteria. It is also recommended that the counties consider collecting subgrade moisture data and perform laboratory testing of subgrade soils to provide more data for evaluation of seasonal variations of deflections.

PAVEMENT DESIGN

Introduction

Information obtained from the survey questionnaire indicated that the majority of the counties use AASHTO, Asphalt Institute, and PEDMOD design procedures for new pavement and overlay designs. New pavement design procedures for all of these methods require resilient modulus values for some or all of the layers in the pavement structure. AASHTO and PEDMOD overlay design procedures also require resilient modulus values for existing layers in the pavement structure and for the overlay material.

It is beyond the scope of this study to describe these design procedures in detail. In the following sections, recommendations for obtaining resilient modulus values for new pavement and overlay design using methods other than backcalculation are given.

New Pavement Design

All three design procedures, PEDMOD, AASHTO, and AI, require the subgrade resilient modulus to accomplish the design. The subgrade resilient modulus at the time of testing can be computed as described above. Some adjustment to the subgrade resilient modulus value obtained at the time of testing will be required depending on the design procedure used. Specific recommendations for obtaining design subgrade resilient modulus values are described in detail in the AASHTO and AI design procedures. In general, adjustments are made for seasonal variability and variability of the subgrade resilient modulus along a road segment, expected traffic, and expected level of performance of the road.

The PEDMOD program is a mechanistic-based design procedure. The design pavement structure is obtained by calculating strains at critical locations in the pavement structure and estimating the number of ESALs to failure for the pavement structure. The design layer thickness is increased until the number of ESALs to failure is equal to the number of ESALs in the design period. When selecting a design subgrade resilient modulus for PEDMOD, seasonal variability, segment variability and expected traffic should be considered as in the other design methods.

When the design is performed, several designs should be obtained for a range of subgrade resilient modulus values to examine the effects of changes in subgrade resilient modulus on the designs obtained. Tables 12 and 13 show new pavement designs obtained for two different cases of county road traffic conditions using these three design procedures for different design subgrade modulus values. The results for the two cases analyzed suggest that pavement designs are more sensitive to design subgrade resilient moduli at lower modulus values.

The AASHTO design procedure requires layer coefficients for all layers in the pavement structure including the surface layer, base layer, and subbase layer, if present. The layer coefficients for surface layers are correlated to the resilient modulus value of the material at a reference temperature of 68°F. Layer coefficients for unstabilized materials are correlated to several material properties including resilient modulus, CBR, Stabilometer R-value, and Texas Triaxial Test values. The following resilient modulus values and corresponding layer coefficients for surface, base and subbase materials may be used in the AASHTO design procedure when no other material property information is available:

Material Type	Resilient Modulus (psi)	Layer Coefficient	AASHTO Default Values
Asphalt Concrete	620,000 @ 68°F	0.42 - 0.44	0.44
Bituminous Surface Treatment	300,000 @ 68°F	0.25 - 0.30	--
Crushed Base Materials	25,000 to 30,000	0.12 - 0.14	0.12-0.14
Gravel Base	15,000 to 20,000	0.10 - 0.12	0.11-0.14

The PEDMOD design procedure requires resilient modulus values for all layers in the pavement structure. The values recommended for the AASHTO design procedure are suitable for unstabilized materials in the base or subbase. Resilient modulus values for AC and BST surface layers should be corrected to a reference temperature of 70°F or 77°F depending on average pavement temperatures in the county. In general, it is anticipated that a reference temperature of 70°F is suitable for counties west of the Cascade Mountain Range and a reference temperature of 77°F is suitable for counties east of the Cascade Mountain Range. The following resilient modulus values correspond to these reference temperatures:

Material Type	Reference Temperature (°F)	Resilient Modulus (psi)
Asphalt Concrete	70	560,000
Asphalt Concrete	77	400,000
Bituminous Surface Treatment	70	300,000
Bituminous Surface Treatment	77	200,000

These recommendations should be used as guidelines. It is recommended that the counties conduct laboratory resilient modulus tests on representative materials used in pavement structures in their county to verify these values.

The Asphalt Institute design procedure does not require resilient modulus values for the surface or base layer. The method does require the MAAT (mean annual air temperature) to select the appropriate design charts for obtaining the pavement surface layer thickness. Based on the information obtained from in this study, it is recommended that the counties use the design charts for a MAAT of 60°F. It is also recommended that individual counties consult published climatic data for their counties to verify that this MAAT is appropriate.

Overlay Design

The AASHTO and PEDMOD overlay design procedures require that the resilient modulus values for the surface, base and subbase layers be known for the existing pavement structure. In order to obtain this information from methods other than backcalculation, laboratory resilient modulus testing on samples obtained from an existing pavement is required. Alternatively, Stabilometer R-value tests or CBR tests on representative samples of unstabilized materials from the base or subbase can be performed, and these values can be correlated to resilient modulus values using the following equations:

$$M_R = 1{,}500\ CBR \qquad (16)$$

where:

M_R = the resilient modulus of an unstabilized material, in psi

CBR = the California Bearing Ratio

and

$$M_R = 1{,}155 + 555\ R \qquad (17)$$

where:

M_R = the resilient modulus of an unstabilized material, in psi

R = the Stabilometer R-value

Once several test results have been obtained for different surface, base and subbase materials, it may be possible to estimate the resilient modulus values using test results on comparable materials and visually inspecting the condition of the surface, base, and subbase. The counties are encouraged to share the results of laboratory resilient modulus tests or other laboratory tests to develop a database of information on pavement layer resilient properties.

This approach to obtaining pavement layer resilient properties for overlay designs is very approximate. Therefore, the counties are encouraged to perform several overlay designs by varying the assumed resilient modulus values of the significant layers in the pavement structure.

The Asphalt Institute presents two methods for designing overlays in MS-17 [1], the Effective Thickness procedure and the Representative Rebound Deflection procedure. The subgrade resilient modulus is required for the Effective Thickness procedure. The design subgrade resilient modulus is obtained in a similar manner to the procedures for new pavement design using the Asphalt Institute method. The effective thickness of the existing pavement structure is obtained by applying the appropriate equivalency factors to each layer in the existing pavement structure. Resilient modulus values are not required to select the appropriate equivalency factors.

The Representative Rebound Deflection method uses the maximum Benkelman Beam deflection to evaluate the required overlay thickness. No pavement layer material properties are required to use this procedure. The Benkelman Beam deflection is obtained from the Road Rater deflection as follows:

$$D_{BB} = 8.0 + 9.1026\ D_{0\ 1,300} \tag{18}$$

where:

D_{BB}	=	the Benkelman Beam deflection, in mils
$D_{0\ 1,300}$	=	the Road Rater deflection normalized to a load of 1,300 pounds, in mils

The Representative Rebound Deflection is obtained from the Benkelman Beam deflection as follows:

$$RRD = (\bar{x} + 2s)(f)(c) \tag{19}$$

where:

RRD	=	the Representative Rebound Deflection, in mils
$\bar{x}$	=	the average Benkelman Beam deflection, in mils over the design unit
s	=	the standard deviation of the Benkelman Beam deflection over the design unit, in mils
f	=	the temperature correction factor for a reference temperature condition of 70°F
c	=	the critical period adjustment factor, which is equal to 1.0 during the most critical time

Two figures are presented in MS-17 to obtain the temperature correction factor, *f*, to correct Benkelman Beam deflections to a reference temperature of 70°F. The critical period adjustment factor, *c*, is applied to adjust the maximum deflection for changes resulting from the effects of moisture only. The critical period adjustment factor is difficult to obtain. Estimates of the critical period adjustment factor can be obtained by maintaining some seasonal correction test factor test sections. Benkelman Beam deflections can be calculated for the test sections and temperature corrections can be applied to the Benkelman Beam deflections. The remaining variation observed in the deflections should be the result of changes in moisture conditions only, provided that the test points are not located in areas that receive significant traffic. The results of the efforts to evaluate seasonal correction factors on the test sections for this study suggest that it is difficult to obtain reliable seasonal adjustment factors for deflections without considerable data.

The counties are encouraged to check overlay designs with one or more different overlay design procedures.

Traffic

An estimate of design life ESALs is required for all of the new pavement and overlay design methods presented. Tables 7 through 9 present load equivalency factors used by WSDOT and the Asphalt Institute for different vehicle types. Both the WSDOT load equivalencies and the load equivalencies from the Asphalt Institute are suitable for use on county roads.

CHAPTER 7

PROCEDURES FOR USING THE ROAD RATER

PERFORMANCE TESTING AND CALIBRATION PROCEDURES

Introduction

Deflection data from a nondestructive deflection testing device are used to characterize properties of materials in a pavement structure and evaluate pavement performance. As with any testing equipment, nondestructive deflection testing equipment must be adequately maintained, properly operated, calibrated, and tested on a regular basis to assure that the data collected during testing are reliable and accurate. This chapter includes recommendations for calibrating and testing the Road Rater and performing deflection tests.

There are two primary components of the Road Rater that should be routinely calibrated and tested. They are the deflection sensors, which on the Road Rater consist of velocity transducers, and the load cell. In addition, periodic testing of the temperature sensor is also recommended.

Four procedures are recommended to check the deflection sensors and/or load cell on the Road Rater to evaluate whether they are functioning properly and giving reliable results. The procedures include:

1. Performance testing of deflection sensors
2. Relative calibration of deflection sensors
3. Approximate verification of the load cell
4. Absolute calibration of the force transducer and deflection sensors

The purpose of and specific details for accomplishing each of these procedures are described below.

Performance Testing of Deflection Sensors

Performance tests are accomplished to indicate generally whether there has been some change in response of the deflection sensors or the load cell. In general, performance tests consist of performing deflection tests in a specified location to determine if the responses of the deflection sensors are consistent. Performance tests should be accomplished in a location with a relatively controlled environment where deflections will not change much as a result of changes in temperature or moisture conditions. An enclosed area with a concrete floor slab that will deflect at least 1 mil at the number one sensor location is recommended. The slab should be in good condition at the location selected for performance testing with no cracks or joints present throughout the area where the deflection sensors will be located. After selecting the general location for the performance tests, the location of the loading plates, deflection sensors and any other contact points on the trailer or vehicle should be permanently marked on the pavement so that tests can be repeated in the same location each time.

The target load for performance tests should be the same as the target load for the Road Rater in the field. For most of the Washington State county Road Raters, the target load is 1,200 pounds force at a frequency of 25 Hertz, although this varies for some of the models. Five consecutive tests should be performed at the same target load level in the test location. Temperature on the slab surface should be measured each time a test is performed.

The data are analyzed by normalizing deflections for each sensor to the standard or target load as described in Chapter 6 using the following equation:

$$D_{iN} = D_i \times \left(P_{standard} / P_{measured}\right) \tag{13}$$

The average normalized deflection from the five tests is calculated and the percent difference between the normalized deflections for each test for each sensor is computed. The percent difference should be less than 5 percent. After verifying that the sensors are performing adequately, the average deflection for each sensor should be plotted on a cumulative deflection versus time graph. If the performance tests indicate that there is less than 5 percent variation in the deflection sensor readings, and the time graph indicates that the deflections are consistent over time, it can be concluded that the deflection sensors and load cell are generally performing adequately.

If the performance tests indicate that there is more than 5 percent variation in one or more of the deflection sensors, the individual sensors exhibiting variability should be checked to verify that the sensor is seated properly, the connections are tight, and there is no loose material on the slab surface at the point of contact. If variations of more than 5 percent are observed at all sensor locations, there may be a problem with the load cell.

Some of the locations selected for performance testing may have slabs that are so stiff that a variation of 5 percent is greater than the level of precision of the sensor. When this occurs, the counties should increase the applied load for performance testing so that a variation of 5 percent of the measured deflection for any sensor is less than the level of precision of the deflection sensor.

At a minimum, performance tests should be accomplished once every week when the equipment is being utilized frequently to obtain field deflection measurements. If the controlled environment in which the performance tests are performed is conveniently located to where the equipment is stored, performance tests should be performed each morning prior to accomplishing field deflection tests.

Appendix E includes an example of the analysis of performance test data and the results.

Relative Calibration of Deflection Sensors

Relative calibration of deflection sensors is performed to make slight adjustments to the calibration factors used in the Road Rater software to determine the measured deflections at each sensor location. A relative calibration is intended only for making small adjustments to the calibration factors for the sensors (less than 5 percent). If a relative calibration procedure indicates that a sensor is more than 5 percent out of calibration based on this procedure, the manufacturer, FMI (Foundation Mechanics Inc.), should be consulted.

As with performance tests, relative calibrations should be accomplished in a location with a relatively controlled environment where deflections will not change much as a result of changes in temperature or moisture conditions. An enclosed area with a concrete floor slab that will deflect at least 1 mil at the number one sensor location is recommended. The location on the slab where a relative calibration will be performed should be in good condition and have no cracks or joints throughout that location. Permanent points should be marked on the slab for the location of the load plates and the location where deflections will be measured.

The methods outlined here generally follow the recommendations outlined by SHRP (Strategic Highway Research Program) [12] for relative calibration of deflection sensors. A relative calibration is performed by mounting the deflection sensors in a frame in which they are stacked one on top of the other. The positions where the deflection sensors are located in the frame are identified with letter designations A through E. Each sensor is numbered 1 through 5.

The test is performed by positioning the load plates and the frame with the stacked deflection sensors at the locations marked on the slab. Care should be taken to position the frame vertically and maintain a vertical alignment during the calibration process. This can be accomplished by mounting a bubble level on the sensor frame. Sensor 1 is in position A, sensor 2 in position B, and so on to sensor 5 in position E. A target load of 1,200 pounds at a frequency of 25 hertz is applied to the slab five times and the deflection is recorded for all sensors in the stack. The sensors are then removed from the frame and repositioned in the stack with sensor 1 in position B, sensor 2 in position C, and so on to sensor 5 in position A. The frame with the stacked deflection sensors is placed back in the designated location and the standard load is again applied five times and deflections are recorded. This procedure is repeated five times until all sensors have occupied all five positions in the stack. This results in 25 deflection sensor readings for each sensor.

The data are analyzed by normalizing all deflection readings to the standard load, as outlined in the section on Performance Testing. The following calculations are then performed:

1. Calculate the average deflection for all tests for all sensors combined.
2. Calculate the average deflection for each sensor for all tests.
3. Calculate the ratio of the overall average to the average deflection for each sensor.

If the value of the ratio of the overall average deflection to the average deflection for each sensor is between 0.95 and 1.05 for all of the deflection sensors, the calibration factors for each deflection sensor will be equal to the ratio value for each sensor. The calibration factors can be adjusted in the Road Rater software by running the SENSMULT program and entering the adjusted calibration factors for each sensor when prompted by the program.

If the ratio value is outside of the range specified above for any deflection sensor, FMI should be consulted. The sensor may be damaged and require replacement.

A relative calibration of the deflection sensors should be performed monthly when the Road Rater is being used frequently. A cumulative graph of calibration factor versus time should be maintained for each deflection sensor. If the calibration factor for one or more deflection sensors are drifting consistently up or down over time, FMI should be consulted.

An example of the calculations to perform a relative calibration of the deflection sensors is shown in Appendix E.

Approximate Verification of the Force Transducer

An approximate verification of the load cell output is accomplished to indicate whether there has been some change in the response of the force transducer. This technique will not uncover variations in output of a few percent; however, it will indicate if some significant variation, that is, greater than 5 percent, in output from the transducer has occurred.

The approximate verification is accomplished by using the transducer to weigh the mass assembly. After the force transducer output is passed through the instrumentation amplifier it gives an output of 0.20 volts/1,000 pounds of force. When the mass is raised from the shock pads by the vibrating cylinder, the total weight of the mass is applied to the force transducer. The weight of the mass is 450 pounds. This force results in an amplified output of 0.090 volts at the output jacks on the J-Box Board. The voltage can be read with a good quality digital voltmeter. A record of the output voltage versus time should be maintained for the force transducer. If changes in the output voltage are observed over time, FMI should be consulted for further assistance with calibrating of the load cell or other assistance as required. If significant changes in the output voltage are observed during verification, the force transducer may have been damaged during use. FMI should be contacted for assistance.

We recommend that an approximate verification of the load cell be accomplished monthly at the same time as the relative calibration of the deflection sensors when the Road Rater is being used frequently or if there is reason to believe that some damage to the loading system may have occurred during deflection testing.

Absolute Calibration of the Force Transducer and Deflection Sensors

Absolute calibration of the force transducer and deflection sensors (velocity transducers) is accomplished to assure that the output from these devices is an indicator of the true value of the measured response, either load, or force, or deflection. Absolute calibration is conducted with specialized equipment under carefully controlled conditions. The absolute calibration of the force transducer and velocity transducers cannot be accomplished by the counties. FMI has the equipment and facilities to perform such testing. It is strongly recommended that the deflection sensors be calibrated annually by FMI. It is also recommended that an absolute calibration of the force transducer be performed annually by FMI.

During 1993, FMI established a temporary calibration facility in Washington state. Absolute calibration of the force transducer and deflection sensors was accomplished for all county Road Raters. This is an efficient, cost-effective method of accomplishing annual absolute calibration of the equipment and it is recommended that the counties and FMI continue to coordinate such efforts.

Additional Comments

Each county that owns and/or operates a Road Rater for pavement deflection testing should have a copy of the manual entitled "Operation's Manual and System Description," by FMI for the Road Rater. The manual includes a general description of the device, descriptions of the hydraulic and electrical systems, instructions on operating the Road Rater, guidelines for service and maintenance, suggestions for field calibrations, information on the temperature measurement instrumentation and capabilities, and data plotting programs. Every individual who is routinely performing pavement deflection testing should be familiar with the information in this manual.

DEFLECTION TESTING PROCEDURES

Introduction

Two types of deflection testing are routinely performed by the counties using the Road Rater. They are:

1. Systemwide testing for pavement system management information
2. Project level testing for design of new pavements and overlays

The procedures for performing deflection testing for each of these purposes are discussed below.

Systemwide Deflection Testing for PMS (Pavement Management System) Level Information

Purpose and Timing. The purpose of performing systemwide deflection testing is to obtain information regarding the structural performance of a road segment or analysis unit over time. Structural performance of a road will be a significant indicator of overall pavement performance when traffic volume is sufficiently high that load-related distress contributes significantly to pavement deterioration. This will generally be the case for a road which is classified as a major collector or higher.

When a road has been recently constructed, reconstructed or received an overlay it is useful to obtain baseline deflection data within six months to one year after construction. Following the initial deflection testing, it is sufficient to perform systemwide testing on the roadway at two- to three-year intervals until such time when some significant loss of performance is observed based on an analysis of the deflection data or on visual pavement condition survey information. After this time, the frequency of deflection testing should be increased to evaluate when rehabilitation is appropriate.

Selection of Analysis Units. The selection of analysis units will be based on two general criteria, pavement structure conditions and traffic conditions. Pavement structure conditions include pavement surfacing type and layer thickness, base layer material type and thickness, and subgrade support conditions. A roadway may extend for several miles; however, pavement structure or traffic conditions may change. When this occurs, the road should be divided into analysis units where the pavement structure and traffic are the same. Further subdivisions may be desirable if analysis units of smaller segments are already identified within a pavement inventory system or pavement management system such as the county road log. The county road log numbering system is a convenient, systematic designation to use for analysis units as well as file designations for the deflection data files.

Testing Procedures. Results of an analysis of pavement structural performance based on deflection data obtained over an analysis unit with the same pavement structure subjected to the same traffic represents the "average" pavement performance of the unit. Therefore, the results should indicate generally how the pavement analysis unit is performing at the time the deflection testing is performed. Changes in average performance should be apparent by changes in the average deflection response between test periods.

Many local phenomena can occur at specific locations in an analysis unit that can result in considerable variability in observed pavement response and performance over the length of the analysis unit. In order to observe changes in pavement performance over time, it is recommended that deflection tests are performed in the same location every year that testing is done on an analysis unit. This can be accomplished by using mileposts on the county roads to locate test points on the analysis units. The milepost locations of each test should be recorded in the deflection data file during testing for each test point. If this approach is used every time that deflection tests are performed on an analysis unit over time, the deflection measurements should be within several feet of the same location on the pavement every time.

The spacing of the deflection tests should be at 500 feet to 1,000 feet in each direction along an analysis unit. After the deflection tests are completed in one direction, the Road Rater should return along the analysis unit in the opposite direction to perform deflections tests. The second set of tests should be offset from the first by one-half the distance between test points to get maximum coverage of the roadway. The tests should be performed in the outer wheel path for pavement performance testing.

Design Level Deflection Testing

Design level deflection testing, as the name implies, is performed to obtain information on in-situ pavement layer resilient modulus values for design of new pavements and overlays. It is also a useful tool for delineating locations on a road segment where conditions vary and alternative design recommendations are appropriate.

The primary difference in deflection testing procedures for systemwide testing and design level testing is the spacing of the test points. Generally, for design level testing, deflection tests should be spaced at 50-foot to 100-foot intervals on the road segment. If there are multiple lanes in each direction on the road, the design lane will be the lane that receives the most traffic loading, which is typically the outer lane. The tests should be performed in the outer wheel path in both directions along the road. The test points in the second or return direction should be offset from the test points in the beginning direction by one-half the distance between test points to obtain maximum coverage of the road.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the research, analysis and results from this study:

1. The counties are generally interested in using the Road Rater for pavement evaluation and design primarily on flexible pavements with AC and BST surfaces and aggregate base layers.
2. The results from the backcalculation analyses indicate that the resilient modulus values obtained using WESDEF will be of limited use to the counties. It is anticipated that counties that continue to perform backcalculation using WESDEF will be required to exercise considerable judgment in interpreting and using the results. It is recommended that alternative deflection-based criteria be used to evaluate pavement structural condition until further studies can be concluded on backcalculation of resilient modulus values using Road Rater data and PEDMOD.
3. Deflection-based criteria recommended for evaluation of pavement performance include the temperature corrected maximum deflection, the temperature corrected area parameter, and the subgrade resilient modulus obtained directly from the deflection at the outer sensor.
4. No recommendations can be made at this time for seasonal correction factors for base, subbase and subgrade materials from the deflection data collected on the test sections during the study. The percent change in subgrade resilient modulus values over the 12-month test period varied from 11 percent to 111 percent, with an average percent change of 37 percent. No general trends in variation of subgrade resilient modulus with time of year, pavement structure type, geographic location or climatic conditions were observed for the data analyzed.
5. The equation for estimating remaining fatigue life in PEDMOD should be changed to the equation developed by Finn [5] for fatigue life. The number of ESALs to a fatigue failure using the equation currently in PEDMOD is 39 percent higher than the number of ESALs to failure obtained using the Finn equation.
6. Reference temperature conditions in PEDMOD should be changed from 90°F to 70°F and 77°F for counties west and east of the Cascade Mountain Range, respectively, to reflect year-round average pavement temperature conditions in these locations.
7. WSDOT load equivalency factors or Asphalt Institute load equivalency factors are recommended rather than the load equivalency factors in PEDMOD for estimating design period ESALs on county roads.
8. Routine performance tests, relative calibration of the deflection sensors, and approximate verification of the load cell should be performed on a regular basis to minimize the potential for collecting unreliable deflection data.

9. Systemwide testing of county roads to evaluate pavement performance should be done on roads with a functional classification of collector or higher. Deflection testing should be performed within the first year after construction of a new pavement or overlay. After this time, deflection testing should be performed at 2- to 3-year intervals with the frequency of testing increasing with pavement age.

10. Counties should continue to collect deflection data on seasonal correction factor test sections using the procedures of this study to evaluate seasonal correction factors that can be applied to deflections and subgrade resilient modulus values. Additional data such as subgrade moisture content, laboratory tests of subgrade soils, and frost depths should also be collected to assist in evaluating seasonal correction factors.

REFERENCES

1. The Asphalt Institute, Asphalt Overlays for Highway and Street Rehabilitation, Manual Series No. 17 (MS-17), The Asphalt Institute, College Park, Maryland, June 1983.

2. The Transportation Research Board, Highway Capacity Manual, Transportation Research Board, National Research Council, Washington, D.C., 1985.

3. The Asphalt Institute, Thickness Design - Asphalt Pavements for Highways and Streets, Manual Series No. 1 (MS-1), The Asphalt Institute, College Park, Maryland, February 1991.

4. The American Association of State Highway and Transportation Officials, AASHTO Guide for the Design of Pavement Structures, The American Association of State Highway and Transportation Officials, Washington, D.C., 1986.

5. Finn, F.N., Saraf, C., Kulkarni, R., Nair, K., Smith, W., and Abdullah, A., "Use of Distress Prediction Subsystems for the Design of Pavement Structures," Proceedings, 4th International Conference on the Structural Design of Asphalt Pavements, University of Michigan, 1977.

6. The Asphalt Institute, Research and Development of The Asphalt Institute's Thickness Design Manual (MS-1), Ninth Edition, The Asphalt Institute, College Park, Maryland, August 1982.

7. The Shell International Petroleum Company Limited, Shell Pavement Design Manual, The Shell International Petroleum Company, London, England, 1978.

8. Brown, S.F., Pell, P.S., and Stock, A.F., "The Application of Simplified Fundamental Design Procedures for Flexible Pavements," Proceedings, 4th International Conference on Structural Design of Asphalt Pavements, Ann Arbor, Michigan, 1977.

9. Mahoney, J.P., Sharma, J., and Hallin, J., "Research Summary Report - Evaluation of Present Legislation and Regulation on Tire Sizes," Configurations and Load Limits, Contract Y-2811, Washington State Department of Transportation, Olympia, Washington, 1983.

10. Bubushait, A.A., "Development of a Flexible Pavement Fatigue Model for Washington State," Ph.D. Dissertation, Department of Civil Engineering, University of Washington, Seattle, Washington, 1985.

11. Southgate, H.F., and Deen, R.C., "Temperature Distributions in Asphalt Concrete Pavements," Highway Research Record No. 549, Highway Research Board, Washington, D.C., 1975.

12. The Strategic Highway Research Program, "Reference Calibration of Falling Weight Deflectometers," The Strategic Highway Research Program, The Federal Highway Administration, Washington D.C., 1991.

TABLE 1
COMPARISON OF NUMBER OF LOAD REPETITIONS TO FAILURE FOR TWO FATIGUE FAILURE CRITERIA SURFACE LAYER RESILIENT MODULUS = 400,000 PSI

Maximum Asphalt Layer Tensile Strain (10^{-6} in/in)	Number of Loads to Failure from PEDMOD Fatigue Failure Criteria	Number of Loads to Failure from Finn Fatigue Failure Criteria
50	1.87E+08	1.36E+08
100	1.91E+07	1.39E+07
150	5.04E+06	3.66E+06
200	1.96E+06	1.42E+06
250	9.38E+05	6.81E+05
300	5.15E+05	3.74E+05
350	3.10E+05	2.25E+05
400	2.00E+05	1.45E+05
450	1.36E+05	9.84E+04
500	9.58E+04	6.96E+04

TABLE 2
AVERAGE PAVEMENT TEMPERATURE

Test Section	Average Pavement Temperature (°F)
CL01	63.5
CL02	60.8
CL03	60.2
CL04	62.1
CL05	59.7
FR01	64.6
FR02	68.0
FR03	73.6
P101	62.9
P102	61.0
P104	64.4
P105	62.7
SP01	56.3
SP02	60.7
SP03	61.4
SP04	64.2
SP05	67.8
SP06	61.9
SP07	71.9
WA01	49.1
WA02	57.9
WA03	66.5

TABLE 3
REMAINING LIFE ESTIMATES FOR DIFFERENT SURFACE THICKNESSES AND PAVEMENT TEMPERATURES

Asphalt Concrete Temperature (°F)	Asphalt Concrete Resilient Modulus (Ksi)		Remaining Life					
			2-inch AC		4-inch AC		6-inch AC	
			Subgrade Resilient Modulus 5,000 psi	Subgrade Resilient Modulus 15,000 psi	Subgrade Resilient Modulus 5,000 psi	Subgrade Resilient Modulus 15,000 psi	Subgrade Resilient Modulus 5,000 psi	Subgrade Resilient Modulus 15,000 psi
50	1,270	Rutting	6.91×10^2	1.10×10^4	3.23×10^4	4.25×10^5	5.72×10^5	6.65×10^5
		Fatigue	8.24×10^4	2.11×10^5	8.01×10^5	1.42×10^6	4.18×10^6	7.03×10^6
70	560	Rutting	2.65×10^2	4.37×10^3	6.18×10^3	8.95×10^4	7.39×10^4	8.81×10^5
		Fatigue	4.91×10^4	7.74×10^4	1.62×10^5	2.73×10^5	6.38×10^5	1.09×10^6
90	190	Rutting	1.12×10^2	1.90×10^3	1.20×10^3	1.76×10^4	8.43×10^3	1.15×10^5
		Fatigue	3.86×10^4	4.71×10^4	3.50×10^4	5.27×10^4	8.96×10^4	1.43×10^5

TABLE 4
18 KIP EQUIVALENT AXLE LOAD TIRE PRESSURE AND RADIUS LOADING CONDITIONS

Tire Pressure (psi)	Single Tire Radius of Contact Area (inches)	Dual Tire Radius of Contact Area (inches)
80	5.98	4.23
90	5.64	3.99
100	5.35	3.78

TABLE 5
STANDARD PAVEMENT LAYER COEFFICIENTS IN PEDMOD

Material Type	Layer	Standard Layer Coefficient a_{ls}	Standard Resilient Modulus E_{ls} (psi)	Comments
Asphalt Concrete	Surface	0.44	800,000	Modulus at 68°F
Bituminous Surface Treatment	Surface	0.17	135,000	Marshall Stability = 500
Untreated Aggregate Base	Base	0.14	30,000	From 1986 AASHTO Design Guide
Select Aggregate Base	Base	0.11	15,000	From 1986 AASHTO Design Guide
Select Subbase	Subbase	0.11	15,000	From 1986 AASHTO Design Guide

TABLE 6
LOAD EQUIVALENCY FACTORS FOR DIFFERENT VEHICLE TYPES FROM PEDMOD

Vehicle Type	Load Equivalency Factor
Single Unit 2-Axle Truck	0.20
Single Unit 3-Axle Truck	0.28
Trailer Truck	0.88
Bus	0.22

TABLE 7
LOAD EQUIVALENCY FACTORS FOR DIFFERENT VEHICLE TYPES USED BY WSDOT

Vehicle Type	Load Equivalency Factor
Single Unit Trucks	0.25
Double Unit Trucks	1.00
Train Trucks	1.75

TABLE 8
LOAD EQUIVALENCY FACTORS FOR RURAL ROAD SYSTEMS FROM THE ASPHALT INSTITUTE

Vehicle Type	Interstate	Other Principal	Minor Arterial	Major Collectors	Minor Collectors	Range
Single-unit Trucks						
2-axle, 4-tire	0.003	0.003	0.003	0.017	0.003	0.003-0.017
2-axle, 6-tire	0.21	0.25	0.28	0.41	0.19	0.19-0.41
3-axle or more	0.61	0.86	1.06	1.26	0.45	0.45-1.26
All single units	0.06	0.08	0.08	0.12	0.03	0.03-0.12
Tractor Semitrailers						
4-axle or less	0.62	0.92	0.62	0.37	0.91	0.37-0.92
5-axle	1.09	1.25	1.05	1.67	1.11	1.05-1.67
6-axle or more	1.23	1.54	1.04	2.21	1.35	1.04-2.21
All multiple units	1.04	1.21	0.97	1.52	1.08	0.97-1.52
All Trucks	0.52	0.38	0.21	0.30	0.12	0.12-0.52

TABLE 9
LOAD EQUIVALENCY FACTORS FOR URBAN ROAD SYSTEMS FROM THE ASPHALT INSTITUTE

Vehicle Type	Interstate	Other Freeways	Other Principal	Minor Arterial	Collectors	Range
Single-unit Trucks						
2-axle, 4-tire	0.002	0.015	0.002	0.006	--	0.006-0.015
2-axle, 6-tire	0.17	0.13	0.24	0.23	0.13	0.13-0.24
3-axle or more	0.61	0.74	1.02	0.76	0.72	0.61-1.02
All single units	0.05	0.06	0.09	0.04	0.16	0.04-0.16
Tractor Semitrailers						
4-axle or less	0.98	0.48	0.71	0.46	0.40	0.40-0.98
5-axle	1.07	1.17	0.97	0.77	0.63	0.63-1.17
6-axle or more	1.05	1.19	0.90	0.64	--	0.64-1.19
All multiple units	1.05	0.96	0.91	0.67	0.53	0.53-1.05
All Trucks	0.39	0.23	0.21	0.07	0.24	0.07-0.39

TABLE 10
OVERLAY THICKNESSES FOR
VARIATIONS IN PAVEMENT STRUCTURE AND TRAFFIC CONDITIONS

Design Parameter Varied	Amount	Overlay Thickness (inches)	
		County Road Type 1 2" BST, 9" Select Base	County Road Type 2 4" AC, 9" Aggregate Base
Reference Case - no change	--	2.6	1.7
AC Modulus	+100,000 psi	2.3	1.4
AC Modulus	-100,000 psi	2.8	2.0
AC Reference Temperature	+10°F	3.1	2.2
AC Reference Temperature	-10°F	2.0	1.1
Subgrade Modulus	+5,000 psi	2.6	1.6
Subgrade Modulus	-5,000 psi	4.5	1.7
Traffic Growth Factor	+2 percent	2.7	1.9
Traffic Growth Factor	-2 percent	2.4	1.5

TABLE 11
OVERLAY DESIGNS OBTAINED USING PEDMOD, AASHTO AND ASPHALT INSTITUTE PROCEDURES

Design Procedure	Overlay Thickness (inches)	
	County Road Case 1 2" BST, 9" Select Base	County Road Case 2 4" AC, 9" Aggregate Base
PEDMOD	2.6	1.7
AASHTO	1.6	None required
AI Effective Thickness	3.1	2.4

TABLE 12
NEW PAVEMENT DESIGNS USING PEDMOD, AASHTO AND ASPHALT INSTITUTE FOR LOW-VOLUME COUNTY ROAD CASE

Design Layer	Design Method	AC Surface Layer Thickness (inches)	Aggregate Base Layer Thickness (inches)	Subgrade Modulus (psi)
Surface	PEDMOD	3.9	9.0	10,000
	AASHTO	2.6	9.0	10,000
	AI	4.0	9.0	10,000
Base	PEDMOD	4.0	8.1	10,000
	AASHTO	4.0	4.2	10,000
	AI	–	–	10,000
Surface	PEDMOD	3.2	9.0	15,000
	AASHTO	1.9	9.0	15,000
	AI	3.5	9.0	15,000
Surface	PEDMOD	5.4	9.0	5,000
	AASHTO	4.0	9.0	5,000
	AI	6.5	9.0	5,000

TABLE 13
NEW PAVEMENT DESIGNS USING PEDMOD, AASHTO AND ASPHALT INSTITUTE FOR HIGH-VOLUME COUNTY ROAD CASE

Design Layer	Design Method	AC Surface Layer Thickness (inches)	Aggregate Base Layer Thickness (inches)	Subgrade Modulus (psi)
Surface	PEDMOD	5.2	9.0	15,000
	AASHTO	3.0	9.0	15,000
	AI	6.0	9.0	15,000
Surface	PEDMOD	5.1	9.0	20,000
	AASHTO	2.5	9.0	20,000
	AI	5.0	9.0	20,000
Surface	PEDMOD	5.3	9.0	10,000
	AASHTO	3.8	9.0	10,000
	AI	7.0	9.0	10,000

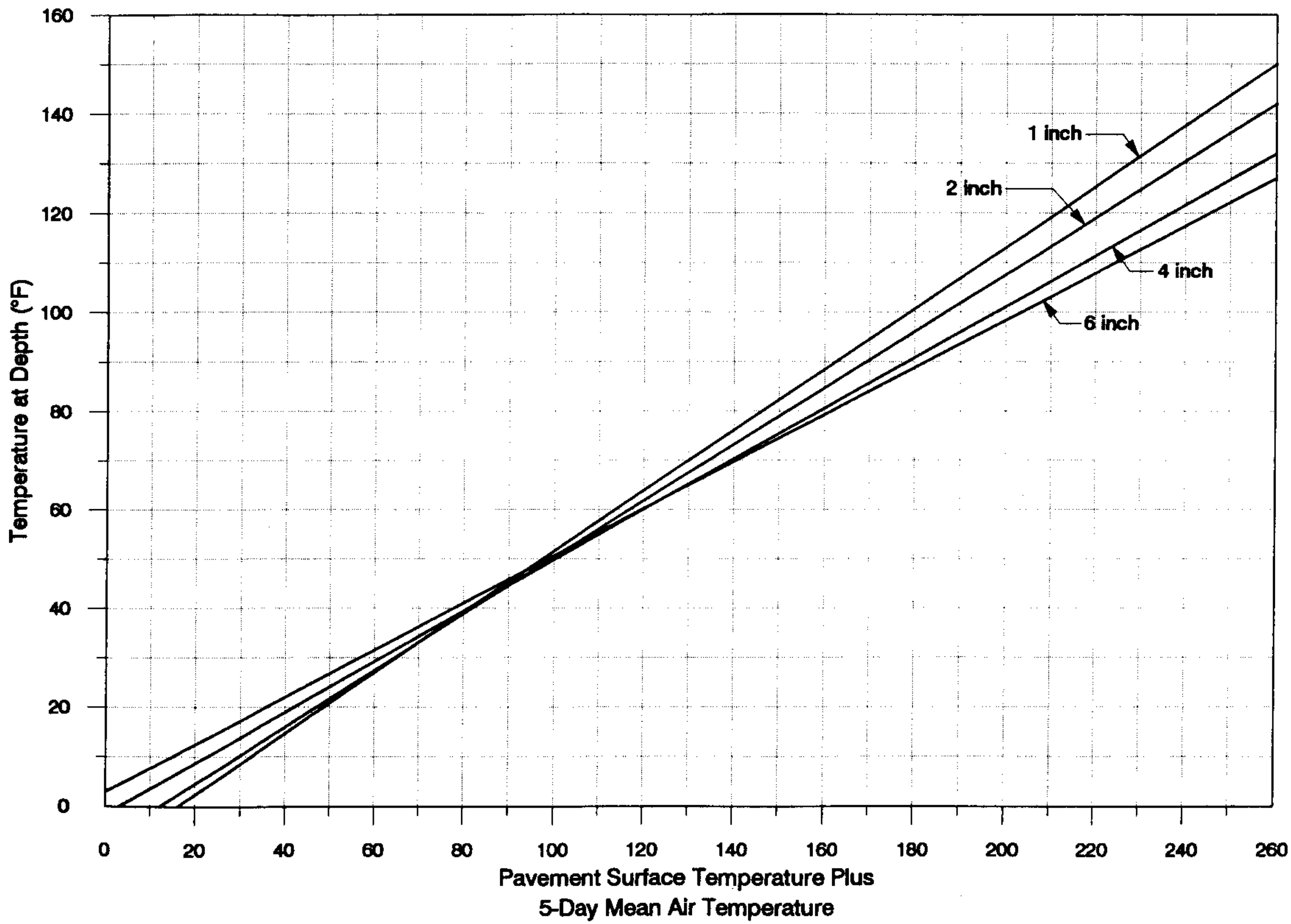


Figure 1. Estimation of Pavement Temperature

APPENDIX A

APPENDIX A

SUMMARY OF RESULTS
BACKGROUND INFORMATION QUESTIONNAIRE
WSDOT ROAD RATER STUDY

GENERAL

Questionnaires were sent to 39 counties (all counties in Washington State).

Questionnaires were completed by the following 17 counties: Benton, Chelan, Clark, Columbia, Franklin, Garfield, Grays Harbor, King, Lewis, Mason, Pierce, Snohomish, Spokane, Thurston, Walla Walla, Whatcom, and Yakima.

Thank you for your participation.

I. PAVEMENT SYSTEM INFORMATION

1. How many centerline miles of road does your county manage? 17 responses

   Total miles = 20,606
   Average miles/county = 1,212
   Minimum miles/county = 475
   Maximum miles/county = 2,963

2. What percentage of your county is classified as urban, suburban, and rural? 13 responses

	Range in Percent
Urban	0-94
Suburban	0-16
Rural	0-100

3. What percent of centerline miles of your roadway system consists of aggregate surfaced roads, concrete pavements, bituminous surface treatments, and asphalt concrete?

   17 responses

Surface Type	Percent by County	Total Miles
Aggregate Surface	1-63	4,518
BST	4-79	9,033
ACP	0-86	6,440
PCC	0-2	186

4. For which of the four surface types in question 3 do you or would you like to use the Road Rater for pavement structural analysis and design activities? 17 responses

Aggregate	6
BST	16
ACP	14
PCC	5

5. Sketch "typical" pavement structures that would be encountered in your county. Include the following information: pavement structure layer materials and thicknesses down to and including the subgrade, shoulder construction or curbs, surface and/or subsurface drainage measures such as ditches, catch basins, edge drains, etc., typical age(s), number of lanes, an estimate of average daily traffic per lane, and depth to rock if less than 20 feet. Include as many sketches as necessary to characterize the various pavement structures found in your county. If some of the pavement structures are only used in certain areas or in certain climate conditions, please specify.

BST Pavement Summary

Surfacing:	1"-6"	(typically 1"-4")
Base:	2"-4"	Crushed Surfacing top course
	+0"-12"	Crushed Base
	or 4"-12"	Ballast
	or 0"-12"	Gravel Base
	or 0"-12"	Pit Run

AC Pavement Summary

Surfacing:	2"-6"	AC (typically 2"-4")
Base:	1"-4"	Crushed Surfacing Top Course
	or 6"	Crushed Base
	+0"-12"	Gravel Base or Other

A few PCC Pavement Sections
Sandwiched Pavements
Some AC + ATB Pavements

II. MATERIALS

1. What types of surfacing materials have been used to construct county pavements? List surfacing type and approximate percentage of centerline miles of each type.

   Aggregate
   BST
   ACP
   PCC

2. What types of base materials have been used to construct county pavements? List base material type and approximate percentage of centerline miles of each type. Be as specific as possible when describing materials. If you know or can reasonably estimate the percent of fines in unbound base materials, include this information. Be sure to include a category of "no base material" if it applies.

   Crushed Surfacing Top Course, Crushed Base, Gravel Base, Ballast, Pit Run, No Base

3. What types of subbase materials have been used to construct county pavements? List subbase material types and approximate percentage of centerline miles of each type. Be specific about materials. Describe materials and use AASHTO classifications or USCS classifications for materials if possible. Be sure to include a category of "no subbase material."

   Sandy soil, Basalt rock, Base material with different size aggregate, Poorly graded sand, silty or clayey gravel, glacial till, gravel borrow, clean gravel

4. What types of subgrade materials are typically encountered beneath your pavements? List subgrade material types and approximate percentage of centerline miles for each subgrade type. Describe materials and use AASHTO classifications or USCS classifications for materials if possible. Following the description, list any material property information that you may have such as CBR or R-values, resilient modulus values, SPT (standard penetration test) values or others. Indicate how these values were obtained.

   Silt (3), Basalt rock, rock, clayey silt, river run gravel, cobbles, silty sand, clayey sand, poorly graded sand, silty gravel, till, gravelly sand, gravelly loam, silty loam, silty gravelly loam, sandy loam, sandy silt

   R values 6-60
   M_R values 15-30
   Sandy silt, CBR value 5

III. ENVIRONMENTAL CONDITIONS

1. Does your county experience ground freezing and thawing in a "typical" climate year? Does this occur throughout all of or a part of your county? If only a part of the county, about what percent of centerline miles are affected by freeze-thaw?

   16 counties experience freeze-thaw; 1 county has no freeze-thaw
   6 counties reported freeze-thaw throughout county
   6 counties reported freeze-thaw in part of the county
   Percent of centerlines miles of freeze-thaw reported were 4, 60, 70, 75, 80, 100

2. If you answered yes to question 1, what is the average depth of ground freezing beneath pavements in your county? What is the basis for your answer?

   Frost depths ranged from 3"-36"
   Basis for responses included experience, estimates, test holes, published information, design frost depths, building codes

3. In areas where ground freezing and thawing occurs, what percentage of centerline miles of road are located in wet climate areas? Note, an answer of 100 percent means that all the roads in areas where freezing occurs are in wet climate areas.

0 to 20 percent	9
20 to 40 percent	1
40 to 60 percent	2
80 to 100 percent	5

4. In wet climate areas where ground freezing and thawing occurs, estimate the percentage of centerline miles of road where the ground water table or a perched ground water table is located within a few feet of the depth to which ground freezing occurs? An answer of 100 percent means that all pavements in wet, freeze-thaw areas have ground water within a few feet of the depth to which ground freezing occurs.

0 to 20 percent	5
20 to 40 percent	2
40 to 60 percent	3
60 to 80 percent	1
80 to 100 percent	2

5. In areas where no ground freezing occurs, what percentage of centerline miles of road are located in wet climate areas?

0 to 20 percent	2
80 to 100 percent	1

6. In wet climate areas where no ground freezing occurs, estimate the percentage of centerline miles of road where the soil within about 3 feet of the pavement surface is saturated some or all year round? If it is only saturated some of the year, about what percent of the time is it saturated?

0 to 20 percent	1
40 to 60 percent	1
80 to 100 percent	1

7. What are typical maximum daily pavement surface temperatures on your roads in August? If the surface temperature is different for different surface types, list each type separately. Note if these are measured temperatures or estimated temperatures. If they are estimated, describe how they were estimated.

Less than 100°F	2
100°F-120°F	9
120°F-140°F	4
Greater than 140°F	2

Temperatures estimated and measured

IV. PAVEMENT ANALYSIS AND EVALUATION

1. Do you use Road Rater or other nondestructive testing data to evaluate structural condition of pavements?

   Yes 13
   No 3
   Other equipment: One county uses an FWD

2. If your answer to question 1 was yes, do you use maximum deflections only to evaluate structural capacity of pavements, or do you use deflection basin information to backcalculate pavement layer material properties?

   Maximum deflection 7
   Deflection basins 9
   Note: Four counties use both

3. Do you perform pavement condition surveys? If yes, are they performed routinely system-wide or on a limited basis? If limited, in what circumstances are they performed and how are the results used?

   Systemwide 12
   Limited 2
   None 2
   Some performed only on arterials

Answer the remainder of the questions in this section if you backcalculate material properties.

4. How do you select your analysis units to evaluate material properties?

   County road log, surface changes, deflection basins, construction, maximum deflections

5. How do you obtain pavement structure layer thicknesses?

   Construction documents, plans 5
   Cores 8
   Some use both

6. How do you select seed moduli, and upper and lower bounds for modulus values for material properties when performing backcalculations?

   Default values PEDMOD 7
   Experience judgment 3
   AASHTO Classification Correlation, AASHTO Design, WSDOT Data, Coring, Trial & Error

7. Do you perform systemwide deflection testing on a regular basis to evaluate the structural condition of the pavement? If yes, what is the approximate spacing of the deflection tests? How frequently do you test your system?

Yes 7; No 5			
Spacing 0.1 miles	5;	0.05 miles	2
Frequency 1 year	4;	3-5 years	1

8. What time of the year do you perform your deflection testing?

Spring-Summer-Early Fall	6
Early Spring after freeze-thaw	2
Fall-Winter-Spring	1
All times	2

9. Do you make adjustments to deflection data prior to performing any analyses when testing at different times of the year? If yes, describe how this is done.

Yes	4
No	5
Temperature adjustments	3
Seasonal adjustments	4

V. ROAD RATER EXPERIENCE

1. Does your county own a Road Rater? If yes, how long have you owned it?

Yes	6	Time: Less than 1 year to 6 years
No	7	
Co-own	4	

2. If you answered no to question 1, have you had deflection testing performed on roads in your county with a Road Rater from another county?

Yes	6
No	3

3. If you answered no to questions 1 and 2, are you thinking about or planning to purchase a Road Rater for your county or having deflection testing performed by another county? If your answer is yes, specify which applies.

Purchase	2
Test	2
No purchase or testing planned	1

Answer the remainder of the questions in this section if you own a Road Rater and/or perform your own deflection testing.

4. Do you measure pavement surface temperature during deflection testing? If yes, is it measured at every testing location or a few times during the testing period? Explain.

Yes	10
Each test location	9
Early, midday	1

5. What load level(s) do you use to perform deflection testing? How many times do you apply the load to the pavement at a single test point? If you apply the load more than one time, do you save deflection data from all load applications? Explain.

1.2 to 1.3 k	9	
1.3 to 1.5 k	1	
Load applied once at each test location	6	(more if results questionable) 3
Multiple load applications	1	

6. What is the spacing between points when you collect deflection data? Do you vary the spacing depending on the intended use of the deflection data? Specify how the spacing varies and explain why this is done.

0.1 mile	9
0.05 mile	1
50 feet for design	1

7. Do you routinely calibrate the load cell and velocity transducers on your Road Rater? If yes, how is this accomplished and how frequently is it done?

Yes	3
No	1

Generally according to Foundation Mechanics Inc. recommendations

8. Have you done any side-by-side deflection testing with other Road Raters or falling weight deflectometers? If yes, what were the results?

Yes	7
Good comparisons	4
Consistently below average	1

VI. TRAFFIC

1. Do you obtain traffic information by performing traffic counts and obtaining vehicle classification information?

Yes	14
No	1
Counts only	1
Both counts and vehicle classifications routinely	2
Classification occasionally	3

2. If you answered yes to question 1, do you perform traffic counts to get systemwide information, or do you perform traffic counts for design of new pavements and/or overlays only?

Systemwide	2
Projects	4
Both systemwide and projects	8
As needed	1

3. If you answered yes to question 1, describe how the information is obtained, i.e., how do you select locations for obtaining traffic information, determine the duration of traffic counts, and decide whether classification information will be obtained, etc.?

Locations selected by traffic/transportation engineers	3
Mechanical counts typical	6
Some manual counts	3
Duration 4 to 7 days reported	

4. What other methods or information do you use to provide traffic information for pavement evaluation and design activities?

   Transportation modeling-origin-destination studies, growth projection, growth direction, proposed development, business-employment information, industry centers, seasonal changes in traffic, traffic counts combined with MS-17, manual truck counts if warranted.

5. How do you select traffic growth factors and truck growth factors?

Historical traffic count data	6
Planning/transportation department recommendations	3
WSDOT growth factors	2

   Other methods reported include traffic counts and population statistics, MS-17, Highway Capacity Manual, truck growth equal to traffic, no growth factors

6. What method(s) do you use to calculate equivalent axle loads (EALs) for different vehicle classifications?

Asphalt Institute MS-1, MS-17	9
AASHTO	6
PEDMOD	3
WSDOT	1
No EALs calculated	2

VII. NEW PAVEMENT AND OVERLAY DESIGN

1. What pavement design method(s) are you familiar with for new pavement design? For overlay design?

Asphalt Institute MS-1	4;	MS-17	6;	DAMA	3
AASHTO	7				
WSDOT	7				
PEDMOD	6				
Rational Method	2				
County standards	3				

2. What design method(s) does your county use for new pavement construction? For overlay design?

Asphalt Institute MS-1	3;	MS-17	5;	DAMA	1
PEDMOD	5				
AASHTO	4				
WSDOT	4				
County standards	2				
WSDOT standards	1				

3. How do you obtain material properties to use for design for new pavement construction? For overlay construction?

WSDOT laboratory	10
Road Rater	3
AASHTO Classification, correlation	2
Visual identification, correlation	2
Deflection testing (FWD) and coring	1
County Soil Survey, Soil Conservation Service 1 each	

4. Do you check your design using another pavement or overlay design method? Never? Sometimes? Always? If you answered sometimes or always, what method(s) do you use?

Always	4
Sometimes	6
Never	4
Check WSDOT against AI	
AASHTO against AI, Rational Method	
PEDMOD against AI	
AASHTO against DAMA	

5. When you are doing an overlay design, how do you obtain layer thickness information?

Coring	8
Plans	4
Overlay history	1
Experience	1

VIII. PERSONNEL

1. How many individuals are involved in pavement testing, analysis, design and pavement management activities in your county?

0-1	3
2-3	5
4-5	4
6-7	3
8-9	0
10+	1

2. Approximately how many person-hours per year are allocated to these activities?

0 - 1,000	8
1,000 - 2,000	1
2,000 - 3,000	2
3,000 - 4,000	3
11,000 - 12,000	2

3. List the titles of personnel involved in pavement testing, analysis, design and pavement management activities in your county. Next to the title, indicate the amount and type of education required as stated in the job description.

   High school - part-time
   Technical degree - related experience
   2-yr civil engineering/engineering tech degree
   B.S.C.E.
   Professional engineer
   Ph.D.

4. Have some of the personnel involved in pavement testing, analysis, design and management activities attended short courses on these topics? If yes, indicate which individuals by job title and give the name of the course and when and where it was attended.

   Road Rater Conference
   User Group Meetings
   Pavement Rating Classes
   Pavement Design/Pavement Management Classes with FHWA, WSDOT
   Asphalt Institute Short Course

5. Are individuals responsible for the pavement activities listed in the previous questions also responsible for other county engineering activities outside of pavement related activities? If yes, list the individual(s) by title and indicate approximately what percentage of their time is dedicated to pavement related activities in a typical year.

Other responsibilities	13
Full-time	2

APPENDIX B

TABLE B1 (Page 1 of 4)
TEST SECTIONS FOR SEASONAL CORRECTION FACTORS

Test Section	County	Location	Pavement Structure
CL01	Clark	Northeast 83rd Street, between I-205 and 94th Avenue, westbound lane	Surfacing: 4.2 inches Class B AC Base: 13.8 inches crushed aggregate Subbase: – Subgrade: Gravelly loam
CL02	Clark	63rd Street Northeast, west of Anderson, bottom of hill where recent overlay has been constructed	Surfacing: 3.8 inches Class B AC Base: 11.2 inches crushed aggregate Subbase: – Subgrade: Loam
CL03	Clark	Northwest 9th Avenue, Northwest 87th Street to Northwest 90th Street, in middle two-way left turn lane	Surfacing: 4.6 inches Class B AC Base: 8 inches crushed aggregate Subbase: 8 inches pit run gravel Subgrade: Silt loam
CL04	Clark	Northeast 119th Street, 152nd Avenue to 172nd Avenue	Surfacing: 1.8 inches BST Base: 12 inches pit run gravel Subbase: – Subgrade: Loam
CL05	Clark	139th Street Northwest, new construction, near Northwest 21st Avenue	Surfacing: 6.6 inches Class E + 1.8 inches Class B Base: 3.6 inches crushed surfacing Subbase: – Subgrade: Silt loam
FR01	Franklin	Glade Road North, south of Clark Road	Surfacing: 4.2 inches Class B Base: 9 inches crushed surfacing Subbase: – Subgrade: Sand
FR02	Franklin	East Foster Wells Road, fill section	Surfacing: 1.5 inches BST Base: 9 inches crushed surfacing Subbase: – Subgrade: Fine sand with silt
FR03	Franklin	Burr's Canyon Road, fill section	Surfacing: 1.5 inches BST Base: 9 inches crushed surfacing Subbase: – Subgrade: Fine sand
PI01	Pierce	Canyon Road, between 192nd South and 186th South, southbound lane	Surfacing: 3 inches Class B AC Base: 2 inches crushed surfacing + 12 inches gravel base Subbase: – Subgrade: Sandy gravel
PI02	Pierce	194th Avenue, between 144th Street South and 136th Street South, southbound lane	Surfacing: 2.5 inches BST + 1.8 inches AC Base: 12 inches gravel base Subbase: – Subgrade: Glacial till

TABLE B1 (Page 2 of 4)

Test Section	County	Location	Pavement Structure
PI03	Pierce	136th Street East, east of 114th Avenue South	Test section omitted
PI04	Pierce	Woodland Avenue, starting south of intersection of 113th Court East	Surfacing: 2 to 2.5 inches BST Base: – Subbase: – Subgrade: Glacial till
PI05	Pierce	Pioneer Way, east of Woodland Avenue, fill section with no distress	Surfacing: 3 inches Class B AC Base: 2 inches crushed surfacing + 12 inches gravel base Subbase: – Subgrade: Silty sand fill over peat
SN01	Snohomish	300th Street Northwest, west of 40th Avenue Northwest (Lund Road), eastbound lane	Surfacing: 6 inches Class B AC Base: 6 inches gravel base Subbase: – Subgrade: Gravelly silty sand
SN02	Snohomish	Getchell Road, approximately 0.8 mile east of Hwy. 9, westbound lane	Surfacing: 4.8 inches Class B AC Base: 12 inches gravel base Subbase: – Subgrade: Glacial till
SN03	Snohomish	Marsh Road, approximately 0.15 mile west of Hwy. 9, eastbound lane	Surfacing: 7.2 inches Class B AC Base: 7 inches gravel base Subbase: 10 inches glacial till fill Subgrade: Sand and silt
SN04	Snohomish	180th Avenue Southeast, starting at 25th Drive, going west in center turning lane	Surfacing: 7.2 inches Class B AC Base: 11 inches crushed surfacing Subbase: – Subgrade: Silty fine to medium sand
SP01	Spokane	Spotted Road, north of Oregon	Surfacing: 2 inches BST Base: 6 inches gravel base Subbase: 12 inches pit run sand and gravel Subgrade: Silty sand
SP02	Spokane	Bruce Road, north of Peone, northbound lane	Surfacing: 3.5 inches Class B AC Base: 5 inches crushed surfacing Subbase: 28 inches pit run sand and gravel Subgrade: Fine sandy silt
SP03	Spokane	University Road, between 16th and 24th Avenue	Surfacing: 4 inches Class B AC Base: 8 inches crushed surfacing Subbase: – Subgrade: Silty sand

TABLE B1 (Page 3 of 4)

Test Section	County	Location	Pavement Structure
SP04	Spokane	North Kantuck Trails, east of Cahill	Surfacing: 1 inch BST Base: 22 inches pit run sand and gravel Subbase: – Subgrade: Silty sandy clay; basalt at 7 feet
SP05	Spokane	Cheney-Spokane, rock cut south of intersection with Groves	Surfacing: 2.5 inches Class B AC Base: 6 inches crushed surfacing Subbase: – Subgrade: Fractured basalt
SP06	Spokane	Brooks Road, between Hallett Road and Thorpe Road	Surfacing: 2 inches Class B AC + 4 inches crushed surfacing over 4 inches BST Base: 8 inches pit run sand and gravel Subbase: – Subgrade: Silty sand
SP07	Spokane	Woods Road, north of Bowie	Surfacing: 3 inches BST Base: 3 inches gravel base Subbase: 18 inches pit run sand and gravel Subgrade: Silty sand
WA01	Walla Walla	McDonald Road, between Hwy. 12 and river crossing	Surfacing: 3.5 inches Class B AC Base: 3 inches crushed surfacing + 9 inches ballast Subbase: – Subgrade: Sandy gravel with a trace of silt
WA02	Walla Walla	Touchet Road, approximately 0.2 mile north of intersection with Legrow Road, fill section	Surfacing: 2 inches BST Base: 3 inches crushed surfacing + 9 inches gravel base Subbase: – Subgrade: Silt
WA03	Walla Walla	Touchet Road, new construction between Plucker Road and the Touchet River crossing	Surfacing: 3.5 inches Class B AC Base: 3 inches crushed surfacing + 9 inches ballast Subbase: – Subgrade: Sandy silt
WH01	Whatcom	Axton Road, east of Aldrich Road, westbound lane	Surfacing: 7.5 inches Class B AC Base: 6 inches gravel base Subbase: – Subgrade: Sandy silt
WH02	Whatcom	West Pole Road, west of Old Guide Road, eastbound lane	Surfacing: 7.5 inches Class B AC Base: 2 inches gravel base Subbase: – Subgrade: Sandy silt
WH03	Whatcom	Haynie Road, east of Schoolhouse Road, eastbound lane	Surfacing: 1 inch BST Base: 7 inches gravel base Subbase: – Subgrade: Silt

TABLE B1 (Page 4 of 4)

Test Section	County	Location	Pavement Structure
WH04	Whatcom	Hampton Road, east of section line, west of North Wood Road, eastbound lane	Surfacing: 7.5 inches Class B AC Base: 6 inches gravel base Subbase: -- Subgrade: Fine sandy silt
WH05	Whatcom	South Pass Road, west of Oat Coals Road, westbound lane	Surfacing: 7.5 inches Class B AC Base: 6 inches gravel base Subbase: -- Subgrade: Fine sandy silt
YA01	Yakima	Summitview Avenue, between 82nd Avenue and 84th Avenue	Surfacing: 3.6 inches Class B AC Base: 3 inches crushed surfacing + 9 inches ballast Subbase: -- Subgrade: Fine sandy silt
YA02	Yakima	Naches-Tieton Road, between Harket Road and Beffa Road	Surfacing: 6 inches Class B AC Base: 8 inches ballast Subbase: -- Subgrade: Fine sand with silt
YA03	Yakima	North Harrah Road, south of Evans Road	Surfacing: 4 inches BST Base: 8 inches ballast Subbase: -- Subgrade: Silt with a trace of fine sand
YA04	Yakima	Sheller Road, east of Franks Road	Surfacing: 3 inches BST Base: 8 inches ballast Subbase: -- Subgrade: Silt with fine sand

TABLE B2
TEST SECTION DEFLECTION DATA

Test Section	Month											
	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
CL01	■	■	■	■	■	■	■	■	■	■	■	■
CL02	■	■	■	■	■	■	■	■	■	■	■	■
CL03	■	■	■	■	■	■	■	■	■	■	■	■
CL04	■	■	■	■	■	■	■	■	■	■	■	■
CL05		■	■	■	■	■	■	■	■	■	■	■
FR01	■	■	■	■	■			■	■	■	■	■
FR02	■	■	■	■	■			■	■	■	■	■
FR03			■	■	■			■	■	■	■	■
PI01	■	■	■	■	■	■	■	■	■	■	■	■
PI02	■	■	■	■	■	■	■	■	■	■	■	■
PI03	■	■	■	■								
PI04	■	■	■	■	■	■	■	■	■	■	■	■
PI05	■	■	■	■	■	■	■	■	■	■	■	■
SN01		■		■								
SN02		■		■								
SN03		■		■								
SN04		■		■								
SP01	■	■	■	■	■		■	■	■	■	■	■
SP02	■	■	■	■	■		■	■	■	■	■	■
SP03	■	■	■	■	■		■	■	■	■	■	■
SP04	■	■	■	■	■		■	■	■	■	■	■
SP05	■	■	■	■	■		■	■	■	■	■	■
SP06	■	■	■	■			■	■	■	■	■	■
SP07	■	■	■	■			■	■	■	■	■	■
WA01	■	■	■	■	■			■	■	■	■	■
WA02	■	■	■	■	■			■	■	■	■	■
WA03					■			■	■	■	■	■
WH01		■	■	■	■	■	■	■	■		■	■
WH02		■	■	■	■	■	■	■	■		■	■
WH03		■	■	■	■	■	■	■	■		■	■
WH04		■	■	■	■	■	■	■	■		■	■
WH05		■	■	■	■	■	■	■	■		■	■
YA01	■	■	■	■								
YA02	■	■	■	■								
YA03	■	■	■	■								
YA04	■	■	■	■								

Note: Shaded boxes indicate that deflection data were collected for these months.

APPENDIX C

TABLE C1 (Page 1 of 2)
BACKCALCULATION RESULTS -- SURFACING LAYER
CLARK COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December	Pavement Surface Temperature
1	1	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Aug. - 119 deg
	2	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Sept. - 80 deg
	3	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Oct. - 61 deg
	4	896,063	1,000,000	1,000,000	1,000,000	1,000,000	Nov. - 49 deg
	5	643,568	1,000,000	1,000,000	1,000,000	1,000,000	Dec. - 40 deg
	6	411,116	1,000,000	1,000,000	1,000,000	1,000,000	
	7	552,941	1,000,000	1,000,000	1,000,000	1,000,000	
	8	673,976	1,000,000	1,000,000	1,000,000	1,000,000	
	9	284,564	1,000,000	1,000,000	1,000,000	1,000,000	
	10	376,812	1,000,000	1,000,000	1,000,000	1,000,000	
2	1	200,000	675,267	1,000,000	1,000,000	1,000,000	Aug. - 96 deg
	2	626,784	1,000,000	1,000,000	1,000,000	1,000,000	Sept. - 79 deg
	3	900,368	1,000,000	1,000,000	1,000,000	1,000,000	Oct. - 60 deg
	4	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Nov. - 49 deg
	5	559,655	1,000,000	1,000,000	1,000,000	1,000,000	Dec. - 40 deg
	6	898,277	1,000,000	1,000,000	1,000,000	1,000,000	
	7	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	
	8	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	
	9	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	
	10	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	
3	1	672,938	1,000,000	1,000,000	1,000,000	1,000,000	Aug. - 106 deg
	2	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Sept. - 63 deg
	3	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Oct. - 61 deg
	4	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	Nov. - 49 deg
	5	593,680	1,000,000	1,000,000	1,000,000	1,000,000	Dec. - 42 deg
	6	676,748	1,000,000	1,000,000	1,000,000	1,000,000	
	7	974,776	1,000,000	1,000,000	1,000,000	1,000,000	
	8	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	
	9	623,801	1,000,000	1,000,000	1,000,000	1,000,000	
	10	790,214	1,000,000	1,000,000	1,000,000	1,000,000	
4	1	226,271	1,000,000	1,000,000	202,559	1,000,000	Aug. - 90 deg
	2	1,000,000	1,000,000	1,000,000	1,000,000	206,740	Sept. - 97 deg
	3	519,688	258,219	328,555	1,000,000	1,000,000	Oct. - 64 deg
	4	360,845	232,682	288,879	1,000,000	1,000,000	Nov. - 48 deg
	5	960,954	463,294	1,000,000	1,000,000	1,000,000	Dec. - 37 deg
	6	511,901	321,011	492,348	909,932	461,889	
	7	1,000,000	1,000,000	588,430	772,375	1,000,000	
	8	200,000	200,000	203,108	299,418	216,941	
	9	1,000,000	358,426	494,321	1,000,000	1,000,000	
	10	200,000	319,066	415,259	307,668	309,730	

TABLE C1 (Page 2 of 2)

Test Section	Test Location	August	September	October	November	December	Pavement Surface Temperature
5	1		865,179	1,000,000	1,000,000	1,000,000	Sept. - 76 deg
	2		958,543	1,000,000	1,000,000	1,000,000	Oct. - 66 deg
	3		1,000,000	1,000,000	1,000,000	1,000,000	Nov. - 46.5 deg
	4		754,645	672,036	1,000,000	1,000,000	Dec. - 44 deg
	5		766,517	981,879	1,000,000	1,000,000	
	6		640,818	907,344	1,000,000	1,000,000	
	7		845,872	1,000,000	1,000,000	1,000,000	
	8		957,755	1,000,000	1,000,000	1,000,000	
	9		826,068	1,000,000	1,000,000	1,000,000	
	10		668,068	1,000,000	1,000,000	1,000,000	

TABLE C2 (Page 1 of 2)
BACKCALCULATION RESULTS -- BASE LAYER
CLARK COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	47,126	41,107	48,646	44,742	37,977
	2	44,419	46,968	50,100	51,809	54,551
	3	26,748	39,373	46,624	49,231	50,848
	4	15,159	26,870	33,014	31,623	33,671
	5	25,560	37,055	43,999	43,249	43,859
	6	38,222	38,695	47,766	46,566	46,282
	7	56,014	69,946	81,807	76,593	77,444
	8	57,122	71,976	80,826	80,036	72,818
	9	41,545	36,498	40,619	37,206	39,358
	10	32,507	31,238	36,696	37,802	42,932
2	1	95,508	112,456	98,002	108,444	100,189
	2	57,883	89,376	91,338	81,830	94,393
	3	28,221	52,809	62,587	55,979	58,063
	4	33,279	43,794	58,991	49,592	50,950
	5	71,740	70,587	77,059	77,029	62,872
	6	49,097	63,574	82,210	61,630	55,377
	7	64,736	108,969	124,766	129,878	148,295
	8	54,308	89,045	113,321	102,177	97,014
	9	58,854	68,935	77,217	70,055	72,396
	10	77,236	103,305	115,216	121,147	130,899
3	1	22,832	38,607	46,325	45,949	44,326
	2	19,116	44,783	45,967	50,672	44,818
	3	17,523	51,699	53,070	52,508	54,644
	4	28,658	60,226	54,673	73,563	53,570
	5	28,437	48,402	72,457	54,362	61,106
	6	30,768	45,782	57,093	38,883	38,410
	7	16,496	40,378	45,831	36,369	36,536
	8	22,034	49,866	48,264	42,701	42,959
	9	27,119	49,702	54,266	45,237	47,976
	10	27,835	72,473	100,570	83,489	84,093
4	1	57,219	49,932	50,520	50,347	35,186
	2	57,307	44,552	47,584	39,295	27,803
	3	63,975	65,677	60,698	46,569	29,962
	4	65,928	67,739	65,124	44,348	37,387
	5	42,426	44,010	43,933	40,248	36,021
	6	55,194	61,164	57,795	51,214	47,380
	7	55,584	62,334	67,291	54,032	38,496
	8	68,647	75,286	74,610	62,575	39,677
	9	56,808	83,995	67,057	52,467	37,055
	10	77,116	109,449	70,234	56,353	47,024

TABLE C2 (Page 2 of 2)

Test Section	Test Location	August	September	October	November	December
5	1		5,000	38,040	150,000	150,000
	2		150,000	150,000	150,000	150,000
	3		150,000	150,000	150,000	150,000
	4		71,326	150,000	150,000	150,000
	5		150,000	150,000	150,000	150,000
	6		150,000	150,000	150,000	150,000
	7		150,000	150,000	150,000	150,000
	8		150,000	150,000	150,000	150,000
	9		150,000	150,000	150,000	150,000
	10		150,000	150,000	150,000	150,000

TABLE C3 (Page 1 of 2)
BACKCALCULATION RESULTS -- SUBGRADE LAYER
CLARK COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	13,977	11,323	11,749	10,606	10,550
	2	10,780	9,382	8,866	8,427	7,715
	3	10,146	9,121	8,530	8,001	7,921
	4	10,560	9,161	9,157	8,418	8,096
	5	11,985	10,295	10,242	9,700	9,268
	6	8,584	7,706	7,732	7,367	7,505
	7	7,451	6,649	6,744	6,626	6,262
	8	7,970	7,073	7,370	6,443	6,463
	9	14,241	12,338	12,588	10,570	10,532
	10	13,531	12,350	13,116	10,964	10,676
2	1	13,106	13,120	12,828	11,883	11,764
	2	14,398	14,527	13,843	11,350	11,464
	3	13,088	13,088	12,474	10,875	10,534
	4	11,750	11,840	11,610	10,425	10,810
	5	12,716	12,174	11,685	9,429	9,616
	6	11,639	11,657	11,458	10,625	10,672
	7	10,219	9,706	9,530	8,385	8,344
	8	10,248	9,908	9,740	7,912	7,326
	9	11,813	10,922	10,702	8,144	8,188
	10	13,299	12,744	12,407	10,714	10,075
3	1	12,575	12,404	12,717	10,512	10,097
	2	15,282	13,857	14,528	13,889	13,047
	3	13,120	13,609	13,386	12,292	11,722
	4	16,554	19,219	19,256	16,160	14,469
	5	12,214	13,019	12,339	11,242	10,388
	6	13,645	15,194	15,233	12,640	11,855
	7	11,085	10,808	10,784	9,641	9,206
	8	11,910	12,946	12,507	10,437	10,293
	9	12,476	12,630	13,242	10,837	10,588
	10	12,967	12,742	13,466	13,110	13,035
4	1	13,234	11,948	11,841	12,595	10,952
	2	11,378	11,683	11,784	10,191	10,357
	3	13,729	14,087	12,432	11,848	11,205
	4	13,896	15,734	15,125	12,031	11,435
	5	12,535	14,070	13,156	11,767	12,094
	6	13,548	16,777	16,198	14,724	14,431
	7	9,352	10,250	10,929	9,274	8,550
	8	18,738	19,873	20,002	17,441	15,986
	9	10,893	12,391	12,626	10,380	9,792
	10	19,564	19,478	20,631	15,136	14,423

TABLE C3 (Page 2 of 2)

Test Section	Test Location	August	September	October	November	December
5	1		15,748	15,669	16,982	17,113
	2		18,821	20,406	20,849	19,220
	3		16,177	18,069	19,221	17,797
	4		21,079	21,312	19,423	18,546
	5		21,162	21,309	20,498	20,494
	6		20,490	19,643	16,697	17,120
	7		18,409	18,664	19,084	18,637
	8		19,670	19,519	19,365	18,489
	9		21,722	21,438	22,963	22,841
	10		18,587	19,302	19,120	19,058

TABLE C4
BACKCALCULATION RESULTS -- SURFACING LAYER
FRANKLIN COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December	Pavement Surface Temperature
1	1	200,000	311,091	256,354	200,000	416,791	Aug. - 104 deg
	2	200,000	345,501	208,566	545,948	588,980	Sept. - 81 deg
	3	200,000	336,491	200,000	348,479	344,985	Oct. - 63 deg
	4	200,000	1,000,000	263,956	504,460	588,540	Nov. - 34 deg
	5	200,000	1,000,000	200,000	200,000	229,985	Dec. - 45 deg
	6	775,540	200,000	421,621	699,558	626,360	
	7	200,000	200,000	525,760	532,870	457,644	
	8	200,000	243,132	477,273	200,000	748,763	
	9	371,494	864,229	1,000,000	497,797	530,742	
	10	200,000	435,984	230,131	702,349	559,431	
2	1		359,209	200,000	200,000	200,000	Sept. - 86 deg
	2		228,429	200,000	391,612	200,000	Oct. - 67 deg
	3		200,000	200,000	200,000	200,000	Nov. - 29 deg
	4		200,000	264,335	479,436	331,836	Dec. - 49 deg
	5		220,668	261,046	200,000	200,000	
	6		1,000,000	200,000	200,000	211,975	
	7		503,442	393,594	381,200	205,776	
	8		285,986	200,000	200,000	200,000	
	9		905,379	200,000	204,940	294,050	
	10		200,000	1,000,000	200,000	200,000	
3	1	200,000	235,500	1,000,000	200,000	200,000	Aug. - 116 deg
	2	200,000	200,000	877,847	200,000	200,000	Sept. - 112 deg
	3	288,347	200,000	248,206	200,000	200,000	Oct. - 79 deg
	4	205,578	203,825	227,854	200,000	200,000	Nov. - 42 deg
	5	546,111	204,056	1,000,000	200,000	200,000	Dec. - 46 deg
	6	200,000	200,000	303,139	1,000,000	200,000	
	7	236,695	352,154	461,988	324,402	200,000	
	8	431,655	277,405	397,335	337,321	347,986	
	9	971,777	313,719	200,000	219,131	209,084	
	10	204,027	200,000	200,000	1,000,000	200,000	

TABLE C5
BACKCALCULATION RESULTS -- BASE LAYER
FRANKLIN COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	60,256	69,389	113,913	142,623	127,659
	2	60,010	65,716	112,989	105,850	101,604
	3	69,020	67,889	109,263	112,366	113,036
	4	66,937	53,432	127,525	131,766	104,088
	5	86,830	59,135	129,508	150,000	142,359
	6	53,963	150,000	146,547	150,000	150,000
	7	65,297	118,253	102,526	150,000	139,030
	8	78,417	117,250	132,380	150,000	147,803
	9	57,425	63,949	78,528	150,000	123,012
	10	76,141	77,991	138,764	105,816	110,377
2	1		45,772	50,913	51,485	32,837
	2		56,385	51,072	67,181	57,144
	3		58,800	56,218	55,011	36,074
	4		46,441	40,837	46,693	32,847
	5		43,479	40,243	49,847	30,215
	6		41,204	41,530	50,442	37,534
	7		41,571	50,939	47,398	34,653
	8		52,876	53,356	61,608	47,195
	9		49,744	64,429	51,997	39,711
	10		44,623	38,029	64,395	39,428
3	1	107,395	90,668	65,139	55,800	85,699
	2	86,437	84,368	42,096	88,074	38,190
	3	48,223	83,170	40,174	44,252	38,263
	4	43,209	47,322	36,264	31,805	21,717
	5	42,143	47,220	25,305	28,446	23,436
	6	55,005	53,581	51,145	27,501	25,638
	7	45,348	33,663	32,733	28,863	24,331
	8	35,020	29,960	29,767	28,514	20,546
	9	36,615	55,267	35,307	35,246	32,108
	10	43,393	49,660	33,969	20,919	26,700

TABLE C6
BACKCALCULATION RESULTS -- SUBGRADE LAYER
FRANKLIN COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	10,380	9,898	9,490	8,590	8,298
	2	10,361	9,200	9,057	8,363	8,162
	3	9,956	9,638	9,210	8,147	8,178
	4	10,885	9,484	9,587	8,848	8,441
	5	11,143	10,309	9,997	8,897	8,945
	6	10,316	10,130	9,122	8,460	8,274
	7	11,448	10,448	10,111	8,825	8,844
	8	10,785	10,732	10,199	10,206	9,100
	9	11,237	10,379	9,120	8,834	9,215
	10	9,859	10,397	9,985	8,476	9,288
2	1		18,061	17,773	16,077	15,631
	2		16,991	16,854	18,361	15,463
	3		13,834	14,801	14,745	13,517
	4		15,882	17,572	17,269	16,423
	5		17,833	17,478	17,500	17,686
	6		17,379	19,247	17,658	17,011
	7		15,622	14,091	15,319	14,804
	8		16,146	15,745	16,500	15,944
	9		14,719	14,067	15,710	14,136
	10		18,936	21,299	16,343	16,010
3	1	30,457	31,462	30,522	29,599	25,342
	2	24,721	26,286	26,397	25,283	24,434
	3	27,976	24,933	23,120	22,740	21,242
	4	31,169	30,676	30,326	25,394	25,374
	5	27,683	23,805	28,554	19,287	19,192
	6	26,857	27,766	26,664	26,394	22,922
	7	24,987	27,346	24,276	18,909	17,763
	8	25,931	24,286	22,820	22,182	18,879
	9	25,366	21,870	22,435	19,132	18,714
	10	21,812	19,777	19,876	19,126	17,310

TABLE C7 (Page 1 of 2)
BACKCALCULATION RESULTS -- SURFACING LAYER
SPOKANE COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December	Pavement Surface Temperature
1	1	1,000,000	200,000	200,000	634,315		Aug. - 87 deg
	2	200,000	200,000	200,000	738,936		Sept. - 87 deg
	3	200,000	200,000	200,000	521,528		Oct. - 46 deg
	4	200,000	1,000,000	437,111	200,000		Nov. - 56 deg
	5	200,000	1,000,000	200,000	200,000		
	6	1,000,000	509,262	200,000	200,000		
	7	1,000,000	1,000,000	506,190	200,000		
	8	200,000	238,653	1,000,000	200,000		
	9	200,000	1,000,000	200,000	200,000		
	10	235,496	200,000	399,635	200,000		
2	1	200,000	200,000	200,000	200,000	200,000	Aug. - 116 deg
	2	200,000	1,000,000	1,000,000	200,000	200,000	Sept. - 106 deg
	3	200,000	200,000	1,000,000	200,000	200,000	Oct. - 59 deg
	4	200,000	200,000	1,000,000	200,000	200,000	Nov. - 43 deg
	5	200,000	1,000,000	1,000,000	200,000	200,000	Dec. - 27 deg
	6	200,000	200,000	1,000,000	1,000,000	413,918	
	7	200,000	200,000	1,000,000	1,000,000	200,000	
	8	200,000	200,000	1,000,000	200,000	200,000	
	9	200,000	1,000,000	200,000	200,000	200,000	
	10	200,000	200,000	200,000	200,000	200,000	
3	1	200,000	200,000	1,000,000	1,000,000	200,000	Aug. - 115 deg
	2	200,000	200,000	200,000	200,000	200,000	Sept. - 105 deg
	3	200,000	200,000	200,000	1,000,000	200,000	Oct. - 62 deg
	4	200,000	200,000	200,000	1,000,000	200,000	Nov. - 45 deg
	5	200,000	200,000	1,000,000	1,000,000	200,000	Dec. - 29 deg
	6	200,000	200,000	200,000	1,000,000	200,000	
	7	200,000	200,000	200,000	200,000	200,000	
	8	200,000	200,000	200,000	1,000,000	200,000	
	9	200,000	200,000	1,000,000	1,000,000	200,000	
	10	200,000	200,000	200,000	1,000,000	200,000	
4	1	1,000,000	200,000	1,000,000	1,000,000	1,000,000	Aug. - 121 deg
	2	1,000,000	1,000,000	1,000,000	1,000,000	200,000	Sept. - 112 deg
	3	1,000,000	1,000,000	333,950	200,000	200,000	Oct. - 80 deg
	4	200,000	200,000	200,000	200,000	200,000	Nov. - 42 deg
	5	200,000	200,000	567,923	504,941	1,000,000	Dec. - 35 deg
	6	200,000	200,000	312,800	248,108	200,000	
	7	890,009	200,000	200,000	231,618	200,000	
	8	200,000	200,000	291,857	238,297	1,000,000	
	9	1,000,000	361,635	1,000,000	200,000	1,000,000	
	10	1,000,000	200,000	200,000	200,000	1,000,000	

TABLE C7 (Page 2 of 2)

Test Section	Test Location	August	September	October	November	December	Pavement Surface Temperature
5	1	527,316	1,000,000	666,512	1,000,000	1,000,000	Aug. - 127 deg
	2	1,000,000	200,000	609,057	1,000,000	1,000,000	Sept. - 114 deg
	3	981,624	458,129	848,232	1,000,000	1,000,000	Oct. - 82 deg
	4	200,000	200,000	200,000	1,000,000	200,000	Nov. - 43 deg
	5	200,000	200,000	411,162	1,000,000	1,000,000	Dec. - 37 deg
	6	200,000	200,000	795,700	1,000,000	1,000,000	
	7	360,662	727,238	1,000,000	1,000,000	200,000	
	8	200,000	200,000	704,273	997,331	1,000,000	
	9	200,000	200,000	782,692	1,000,000	1,000,000	
	10	250,101	260,642	1,000,000	1,000,000	1,000,000	
6	1	200,000	988,661	200,000	200,000	1,000,000	Aug. - 124 deg
	2	200,000	200,000	200,000	200,000	1,000,000	Sept. - 107 deg
	3	200,000	1,000,000	1,000,000	1,000,000	200,000	Oct. - 87 deg
	4	200,000	200,000	200,000	200,000	200,000	Nov. - 44 deg
	5	200,000	200,000	200,000	200,000	200,000	Dec. - 38 deg
	6	1,000,000	1,000,000	200,000	200,000	200,000	
	7	200,000	200,000	200,000	200,000	200,000	
	8	200,000	200,000	200,000	200,000	1,000,000	
	9	200,000	200,000	200,000	200,000	200,000	
	10	1,000,000	1,000,000	200,000	200,000	1,000,000	

TABLE C8 (Page 1 of 2)
BACKCALCULATION RESULTS -- BASE LAYER
SPOKANE COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	99,936	99,433	94,605	57,239	
	2	150,000	103,539	149,786	56,398	
	3	120,378	150,000	114,424	72,246	
	4	150,000	83,357	119,418	100,151	
	5	88,739	59,008	150,000	96,615	
	6	96,206	101,139	128,588	52,339	
	7	93,385	84,424	74,535	98,475	
	8	71,145	108,708	73,611	77,485	
	9	150,000	95,344	150,000	93,516	
	10	148,741	115,201	47,441	58,695	
2	1	150,000	150,000	150,000	150,000	150,000
	2	150,000	150,000	150,000	150,000	150,000
	3	150,000	150,000	150,000	150,000	150,000
	4	150,000	150,000	150,000	150,000	150,000
	5	150,000	150,000	150,000	150,000	150,000
	6	150,000	150,000	150,000	150,000	150,000
	7	150,000	150,000	150,000	150,000	150,000
	8	150,000	150,000	150,000	150,000	150,000
	9	150,000	150,000	150,000	150,000	150,000
	10	150,000	150,000	150,000	150,000	150,000
3	1	150,000	150,000	150,000	150,000	150,000
	2	150,000	150,000	150,000	150,000	150,000
	3	150,000	150,000	150,000	150,000	150,000
	4	150,000	150,000	150,000	150,000	150,000
	5	150,000	150,000	150,000	150,000	150,000
	6	150,000	150,000	150,000	150,000	150,000
	7	150,000	150,000	150,000	150,000	150,000
	8	150,000	150,000	150,000	150,000	150,000
	9	150,000	150,000	150,000	150,000	150,000
	10	150,000	150,000	150,000	150,000	150,000
4	1	150,000	150,000	150,000	150,000	150,000
	2	150,000	150,000	150,000	150,000	150,000
	3	150,000	150,000	150,000	150,000	150,000
	4	150,000	150,000	150,000	150,000	150,000
	5	150,000	150,000	150,000	62,582	150,000
	6	150,000	87,840	71,052	60,922	150,000
	7	96,719	69,522	74,516	109,491	150,000
	8	150,000	78,087	92,164	16,384	150,000
	9	67,565	38,461	28,215	30,236	150,000
	10	30,788	35,481	68,997	52,396	150,000

TABLE C8 (Page 2 of 2)

Test Section	Test Location	August	September	October	November	December
5	1	50,246	27,455	42,621	22,909	150,000
	2	41,005	28,999	36,910	11,919	150,000
	3	18,835	17,325	11,777	9,807	150,000
	4	94,821	42,860	73,459	23,677	150,000
	5	55,931	33,161	26,577	16,457	150,000
	6	37,434	23,059	15,715	8,671	150,000
	7	49,196	40,088	27,844	13,428	150,000
	8	23,936	27,186	12,206	8,236	150,000
	9	47,721	33,709	19,092	10,913	150,000
	10	45,525	43,232	20,569	17,567	150,000
6	1	150,000	150,000	150,000	150,000	150,000
	2	150,000	150,000	150,000	150,000	150,000
	3	150,000	150,000	150,000	150,000	150,000
	4	150,000	150,000	150,000	150,000	150,000
	5	150,000	150,000	150,000	150,000	150,000
	6	150,000	150,000	150,000	150,000	150,000
	7	150,000	150,000	150,000	150,000	150,000
	8	150,000	150,000	150,000	150,000	150,000
	9	150,000	150,000	150,000	150,000	150,000
	10	150,000	150,000	150,000	150,000	150,000

TABLE C9 (Page 1 of 2)
BACKCALCULATION RESULTS -- SUBGRADE LAYER
SPOKANE COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	9,471	10,595	11,508	8,158	
	2	12,077	12,318	14,726	9,599	
	3	9,952	10,619	11,997	7,930	
	4	12,095	12,166	13,424	9,630	
	5	12,544	13,476	14,816	10,197	
	6	12,433	12,476	14,588	10,208	
	7	12,030	12,979	16,239	11,598	
	8	12,275	13,975	12,954	11,854	
	9	12,754	12,550	14,749	11,669	
	10	14,649	16,411	16,494	12,937	
2	1	24,313	22,009	21,992	19,955	36,775
	2	20,573	18,247	18,414	17,751	38,782
	3	21,851	20,681	18,435	17,516	40,168
	4	20,457	20,371	20,494	17,972	39,534
	5	23,102	21,504	20,870	18,629	36,948
	6	24,416	23,499	21,355	19,231	46,300
	7	23,358	22,755	20,462	20,382	37,107
	8	23,626	22,926	21,149	20,795	36,510
	9	21,755	18,103	20,787	19,207	38,299
	10	26,524	24,541	26,450	24,438	37,655
3	1	12,076	11,330	10,525	9,992	31,258
	2	18,128	18,539	20,527	17,840	40,445
	3	15,842	14,277	14,944	13,048	35,469
	4	14,780	13,181	14,285	13,273	33,964
	5	14,681	13,663	13,750	13,575	40,127
	6	14,442	13,462	15,308	11,425	40,538
	7	17,498	15,932	17,869	16,306	41,603
	8	13,794	12,878	15,177	12,241	39,764
	9	16,763	14,277	14,576	12,629	37,727
	10	16,585	15,505	14,977	13,192	43,522
4	1	10,105	13,816	12,593	13,357	27,875
	2	6,755	6,907	7,510	9,239	15,289
	3	8,040	8,305	10,286	13,225	21,381
	4	14,672	15,090	14,479	15,318	27,369
	5	14,698	15,973	18,815	23,334	40,385
	6	20,652	23,036	23,508	26,169	42,903
	7	19,848	22,278	20,377	22,991	31,827
	8	31,334	33,916	33,271	44,668	46,926
	9	50,000	44,604	50,000	50,000	50,000
	10	50,000	50,000	50,000	50,000	50,000

TABLE C9 (Page 2 of 2)

Test Section	Test Location	August	September	October	November	December
5	1	30,544	33,854	30,487	29,256	50,000
	2	50,000	50,000	50,000	50,000	50,000
	3	50,000	39,201	40,434	30,655	50,000
	4	22,846	23,925	23,106	17,743	43,201
	5	50,000	40,286	35,450	30,962	50,000
	6	50,000	38,321	41,388	37,708	50,000
	7	27,441	21,720	22,743	18,325	38,227
	8	50,000	35,975	31,274	29,405	50,000
	9	34,623	31,318	28,785	23,070	49,439
	10	43,585	32,024	32,610	26,497	50,000
6	1	17,110	18,037	19,537	18,228	30,461
	2	15,902	18,518	18,444	17,055	28,760
	3	14,266	14,533	14,342	13,743	24,710
	4	13,166	13,321	16,732	14,063	22,399
	5	12,303	12,531	14,011	12,702	26,266
	6	14,496	14,389	17,436	13,047	26,160
	7	17,566	16,965	18,806	16,877	33,535
	8	10,796	12,736	13,745	13,216	29,084
	9	11,103	13,566	12,625	11,380	25,255
	10	14,029	14,075	16,478	12,761	29,817

TABLE C10
BACKCALCULATION RESULTS -- SURFACING LAYER
WALLA WALLA COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December	Pavement Surface Temperature
1	1	200,000	200,000	726,876	290,109	1,000,000	Aug. - 68 deg
	2	200,000	200,000	260,506	447,992	273,314	Sept. - 63 deg
	3	200,000	200,000	1,000,000	1,000,000	200,000	Oct. - 46 deg
	4	1,000,000	200,000	200,000	1,000,000	589,088	Nov. - 28 deg
	5	200,000	219,877	226,609	478,330	534,385	Dec. - 42 deg
	6	700,514	894,869	1,000,000	413,487	412,659	
	7	352,684	894,153	403,792	1,000,000	744,872	
	8	200,000	200,000	200,000	270,546	200,000	
	9	209,921	211,980	305,252	251,507	800,871	
	10	200,000	1,000,000	1,000,000	291,745	200,000	
2	1	474,342	280,452	293,910	200,000	200,000	Aug. - 77 deg
	2	200,000	200,000	200,000	200,000	402,995	Sept. - 71 deg
	3	606,960	759,043	1,000,000	206,035	200,000	Oct. - 48.5 deg
	4	200,000	416,465	304,086	200,000	358,201	Nov. - 31 deg
	5	200,000	1,000,000	200,000	200,000	200,000	Dec. - 42.5 deg
	6	227,328	689,443	303,738	217,915	200,000	
	7	200,000	202,885	200,000	506,405	221,185	
	8	204,256	200,000	200,000	932,273	200,000	
	9	215,935	326,034	274,582	282,644	200,000	
	10	1,000,000	200,000	896,653	200,000	814,519	

TABLE C11
BACKCALCULATION RESULTS -- BASE LAYER
WALLA WALLA COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	100,502	96,571	87,092	112,900	58,858
	2	77,960	95,464	100,211	69,096	73,007
	3	150,000	150,000	114,274	108,407	135,078
	4	43,374	68,583	69,955	52,357	44,238
	5	47,174	43,486	42,839	33,820	24,751
	6	38,705	38,916	34,381	49,809	37,229
	7	55,137	46,264	60,114	57,357	39,859
	8	63,828	61,878	75,411	70,296	68,952
	9	71,836	64,056	65,820	76,211	40,099
	10	79,406	44,974	52,046	71,141	58,904
2	1	45,014	52,236	53,101	55,306	42,605
	2	95,173	80,365	103,873	65,929	50,678
	3	58,867	56,192	57,058	55,796	33,762
	4	58,143	47,811	48,500	55,102	32,428
	5	41,241	29,423	25,929	24,968	29,458
	6	41,067	35,958	41,620	36,341	26,451
	7	32,114	29,992	29,293	20,593	20,298
	8	40,274	28,778	31,477	28,199	22,842
	9	61,282	62,115	53,373	47,462	31,028
	10	74,550	63,319	54,152	50,834	29,664

TABLE C12
BACKCALCULATION RESULTS -- SUBGRADE LAYER
WALLA WALLA COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	December
1	1	16,992	16,607	15,220	13,361	11,953
	2	19,817	18,819	16,681	14,497	13,085
	3	11,960	11,211	9,422	8,576	7,911
	4	11,885	11,119	10,049	9,211	8,545
	5	10,783	10,571	10,146	9,836	8,868
	6	8,873	8,864	7,913	7,341	6,340
	7	7,056	6,893	6,085	5,228	5,067
	8	6,681	7,485	6,221	5,842	5,032
	9	5,540	5,591	5,196	4,926	4,365
	10	6,563	5,591	5,556	4,684	4,847
2	1	32,076	28,123	27,670	24,356	23,463
	2	22,718	18,673	17,573	16,449	14,802
	3	15,798	13,295	13,382	13,210	10,902
	4	25,788	28,677	26,743	24,314	23,213
	5	23,106	20,381	21,474	18,474	14,854
	6	15,753	13,418	14,559	13,383	11,849
	7	11,579	11,554	11,262	8,605	9,933
	8	12,409	12,408	12,112	9,993	10,155
	9	12,994	13,138	13,572	10,810	10,862
	10	11,985	11,927	11,783	10,669	9,862

TABLE C13
BACKCALCULATION RESULTS -- SURFACING LAYER
YAKIMA COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November	Pavement Surface Temperature
1	1	200,000	200,000	392,300	1,000,000	Aug. - 80 deg
	2	344,099	200,000	1,000,000	406,806	Sept. - 72 deg
	3	200,000	200,000	432,236	1,000,000	Oct. - 73 deg
	4	843,014	763,911	1,000,000	1,000,000	Nov. - 36 deg
	5	1,000,000	1,000,000	1,000,000	1,000,000	
	6	1,000,000	1,000,000	1,000,000	1,000,000	
	7	1,000,000	1,000,000	1,000,000	1,000,000	
	8	1,000,000	1,000,000	1,000,000	1,000,000	
	9	200,000	513,790	280,861	1,000,000	
	10	288,518	500,001	654,005	797,854	
2	1	479,778	343,745	622,979	355,593	Aug. - 86 deg
	2	635,417	644,248	763,276	645,504	Sept. - 78 deg
	3	496,104	438,298	311,035	200,000	Oct. - 68 deg
	4	547,859	398,231	628,456	526,639	Nov. - 36 deg
	5	260,300	246,988	559,604	821,983	
	6	319,065	272,304	583,023	200,000	
	7	349,667	380,398	1,000,000	1,000,000	
	8	670,203	485,252	702,341	1,000,000	
	9	701,923	626,218	798,654	1,000,000	
	10	501,642	456,409	378,848	483,300	
3	1	200,000	270,105	200,000	471,871	Aug. - 107 deg
	2	517,486	255,623	440,053	381,595	Sept. - 98 deg
	3	207,242	200,000	200,000	330,051	Oct. - 80 deg
	4	200,000	369,850	254,800	1,000,000	Nov. - 49 deg
	5	346,761	328,332	1,000,000	939,878	
	6	776,026	497,416	200,000	1,000,000	
	7	454,034	256,517	281,513	200,000	
	8	493,595	627,703	453,863	1,000,000	
	9	394,766	600,286	837,761	814,985	
	10	200,000	200,000	655,031	1,000,000	
4	1	200,000	200,000	300,391	471,894	Aug. - 117 deg
	2	200,000	200,000	361,166	562,347	Sept. - 114 deg
	3	200,000	200,000	200,000	200,000	Oct. - 78 deg
	4	200,000	1,000,000	327,825	415,957	Nov. - 53 deg
	5	296,826	203,777	694,455	598,055	
	6	200,000	379,032	1,000,000	1,000,000	
	7	675,560	678,991	1,000,000	1,000,000	
	8	908,503	866,727	1,000,000	1,000,000	
	9	1,000,000	375,720	1,000,000	1,000,000	
	10	507,322	535,655	825,893	362,175	

TABLE C14
BACKCALCULATION RESULTS -- BASE LAYER
YAKIMA COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November
1	1	149,612	125,458	111,468	68,057
	2	95,239	103,273	90,768	67,528
	3	132,355	133,833	112,801	61,337
	4	77,854	72,825	73,444	56,195
	5	37,848	39,008	41,149	35,730
	6	35,113	35,688	33,160	37,606
	7	46,965	42,801	52,801	34,852
	8	49,953	50,118	61,792	57,062
	9	104,565	77,014	103,454	59,570
	10	96,511	75,426	72,995	52,494
2	1	34,062	58,381	50,738	150,000
	2	12,265	12,850	17,325	51,359
	3	16,917	24,365	61,844	121,954
	4	15,009	26,156	19,893	43,997
	5	56,346	66,033	41,635	50,714
	6	47,809	69,755	45,991	150,000
	7	39,452	41,080	15,614	39,153
	8	7,552	15,684	11,725	13,117
	9	8,597	11,427	13,648	17,298
	10	32,884	42,067	69,523	112,963
3	1	109,573	70,777	101,273	55,633
	2	74,618	90,802	77,038	96,406
	3	90,776	94,336	123,055	116,410
	4	96,468	101,366	118,757	150,000
	5	53,054	50,693	32,076	31,573
	6	44,329	60,513	150,000	53,597
	7	94,606	122,175	119,543	150,000
	8	60,344	54,977	92,173	36,286
	9	69,584	53,174	47,742	52,269
	10	84,803	101,526	56,235	43,993
4	1	87,913	82,274	65,535	54,680
	2	97,403	59,818	64,245	68,929
	3	64,854	53,483	82,517	93,960
	4	67,011	40,828	85,587	72,207
	5	46,038	41,424	36,428	31,779
	6	56,405	34,565	29,445	30,975
	7	25,259	21,477	24,903	22,024
	8	11,367	11,819	15,091	13,243
	9	11,788	21,191	16,153	19,561
	10	33,333	28,671	42,073	55,681

TABLE C15
BACKCALCULATION RESULTS -- SUBGRADE LAYER
YAKIMA COUNTY
(Shading indicates absolute % difference > 15%)

Test Section	Test Location	August	September	October	November
1	1	11,531	11,323	11,062	9,246
	2	14,227	13,090	11,270	10,358
	3	15,768	12,516	14,083	10,803
	4	19,279	17,673	17,952	13,206
	5	20,934	19,175	18,784	14,640
	6	28,676	24,705	24,917	18,519
	7	32,905	31,634	29,978	24,479
	8	28,591	23,693	20,661	19,195
	9	13,908	11,824	12,743	10,471
	10	22,055	20,169	19,433	14,838
2	1	13,426	12,223	14,042	13,202
	2	18,478	16,743	19,279	51,359
	3	14,071	12,610	13,141	12,162
	4	12,548	11,340	12,659	12,413
	5	14,824	13,417	14,440	14,072
	6	15,177	13,809	14,795	13,936
	7	15,703	14,662	17,349	15,068
	8	21,128	17,223	19,950	18,056
	9	28,695	24,369	24,839	23,109
	10	18,200	17,167	17,820	15,363
3	1	19,053	18,676	20,031	16,592
	2	15,815	15,032	14,878	12,923
	3	15,180	13,393	14,253	11,473
	4	13,881	12,521	13,537	11,517
	5	16,712	14,659	15,070	12,953
	6	15,886	14,511	13,076	14,564
	7	16,351	14,008	15,615	14,191
	8	19,428	18,069	16,385	14,927
	9	17,626	16,280	18,743	16,022
	10	9,775	8,031	11,050	10,508
4	1	13,020	10,963	12,455	11,014
	2	10,870	10,137	10,561	10,092
	3	12,497	10,784	10,944	10,470
	4	13,054	10,938	11,620	10,385
	5	14,272	12,333	13,357	11,782
	6	13,420	12,668	13,444	11,891
	7	17,585	16,319	14,890	13,903
	8	16,714	14,834	14,798	13,114
	9	13,463	12,071	12,471	10,970
	10	12,577	11,034	11,454	10,293

TABLE C16
BACKCALCULATION RESULTS FOR MODULUS VALUES FOR ALTERNATIVE PAVEMENT STRUCTURES
SPOKANE COUNTY
TEST SECTION 3, OCTOBER

Test Location	Original Case Analyzed	Semi-Infinite Rigid Boundary	Rigid Boundary at 11 feet	Rigid Boundary at 41 feet	Combined AC/Base Layer	AC Thickness Increased by 1 inch	AC Thickness Increased by 2 inches	Base Modulus Fixed at 25,000 psi	AC Modulus Fixed at 875,000 psi
Pavement Modulus (psi)									
1	1,000,000	811,528	1,000,000	1,000,000	388,892	1,000,000	200,000	1,000,000	875,000
2	200,000	200,000	200,000	200,000	350,719	200,000	200,000	1,000,000	875,000
3	200,000	1,000,000	200,000	200,000	447,335	1,000,000	200,000	1,000,000	875,000
4	200,000	1,000,000	200,000	1,000,000	454,907	200,000	200,000	1,000,000	875,000
5	1,000,000	1,000,000	200,000	1,000,000	434,612	200,000	200,000	1,000,000	875,000
6	200,000	911,591	200,000	200,000	355,132	200,000	200,000	1,000,000	875,000
7	200,000	200,000	200,000	200,000	415,960	200,000	200,000	1,000,000	875,000
8	200,000	517,692	200,000	535,252	305,174	200,000	286,345	1,000,000	875,000
9	1,000,000	1,000,000	200,000	1,000,000	429,259	200,000	200,000	1,000,000	875,000
10	200,000	678,252	200,000	774,896	313,758	200,000	200,000	1,000,000	875,000
Absolute Percent Difference in Error									
1	28.1	50.7	48.3	17.7	24.0	23.2	35.4	110.1	31.8
2	63.0	12.0	100.3	44.4	26.6	47.5	32.1	110.6	28.2
3	85.7	63.5	117.7	66.9	39.1	38.6	50.9	127.0	47.9
4	83.4	24.5	114.9	28.9	27.0	63.6	46.4	124.3	43.1
5	36.5	18.2	112.2	24.9	25.0	60.8	44.1	121.7	40.0
6	65.1	11.7	98.2	46.5	24.3	46.7	30.1	106.3	27.2
7	79.1	56.7	113.0	59.0	44.4	60.6	51.8	122.7	48.8
8	51.1	5.1	82.9	9.4	15.8	33.1	10.5	91.4	14.8
9	35.3	15.2	112.3	22.3	17.5	60.1	43.3	121.7	39.2
10	55.2	11.0	86.7	15.2	23.8	37.1	23.7	95.2	22.5
Average Percent Difference in Error									
	58.25	26.86	98.65	33.52	26.75	47.13	36.83	113.10	34.35

TABLE C17
BACKCALCULATION RESULTS FOR AC MODULUS VALUES FOR VARIATIONS IN INPUT PARAMETERS
YAKIMA COUNTY
TEST SECTION 1, OCTOBER

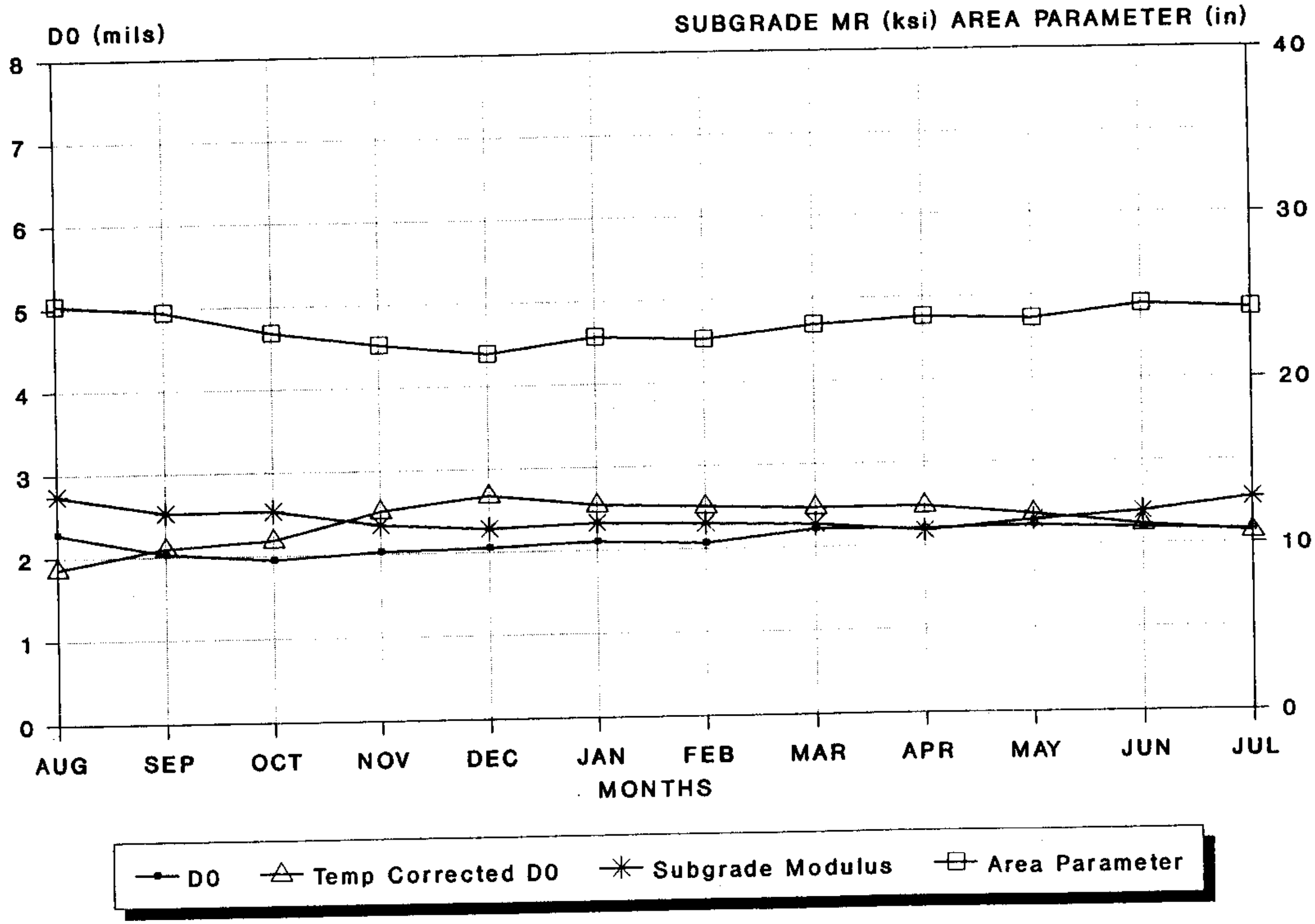
Test Location	Original Case Analyzed	Load +30 lb	Load -30 lb	AC Thickness + 0.5 in	AC Thickness - 0.5 in	Base Thickness + 0.5 in	Base Thickness - 0.5 in	Maximum Deflection 1.02% D0	Maximum Deflection 98% D0
Pavement Modulus (psi)									
1	392,300	237,114	473,209	338,296	236,179	452,699	200,000	200,000	265,057
2	1,000,000	200,000	1,000,000	1,000,000	200,000	200,000	200,000	1,000,000	200,000
3	432,236	405,157	494,481	200,000	200,000	263,033	345,328	267,428	275,076
4	1,000,000	1,000,000	714,225	604,910	456,240	812,310	714,739	1,000,000	772,113
5	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
6	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
7	1,000,000	1,000,000	1,000,000	936,764	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
8	1,000,000	1,000,000	1,000,000	956,266	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
9	280,861	296,536	265,325	263,044	306,094	310,993	251,661	237,730	333,054
10	654,005	753,694	617,779	439,132	566,672	887,963	621,931	423,978	758,430
Absolute Percent Difference in Error									
1	8.1	6.7	9.1	9.4	7.4	9.1	9.0	7.2	7.0
2	24.2	26.0	29.4	31.3	22.2	20.1	27.9	28.4	24.2
3	10.5	10.0	11.5	8.8	9.7	8.8	11.4	10.8	8.6
4	12.6	11.9	12.4	11.7	16.6	13.3	11.6	13.0	13.2
5	20.2	20.8	20.1	20.4	22.4	20.7	19.5	21.3	20.8
6	42.6	43.2	39.4	36.6	44.9	43.7	42.8	42.2	43.3
7	33.3	33.8	34.4	35.1	33.6	34.0	33.7	35.6	32.6
8	15.6	16.0	14.9	14.8	18.9	15.9	15.1	15.3	17.6
9	2.9	2.6	3.8	3.4	2.8	2.3	5.4	7.4	3.1
10	10.0	9.9	9.8	8.8	9.7	11.5	9.5	8.0	9.4
Averge Percent Difference In Error									
	18.00	18.09	18.48	18.03	18.82	17.94	18.59	18.92	17.98

TABLE C18
BACKCALCULATION RESULTS FOR BST MODULUS VALUES FOR VARIATIONS IN INPUT PARAMETERS
YAKIMA COUNTY
TEST SECTION 3, OCTOBER

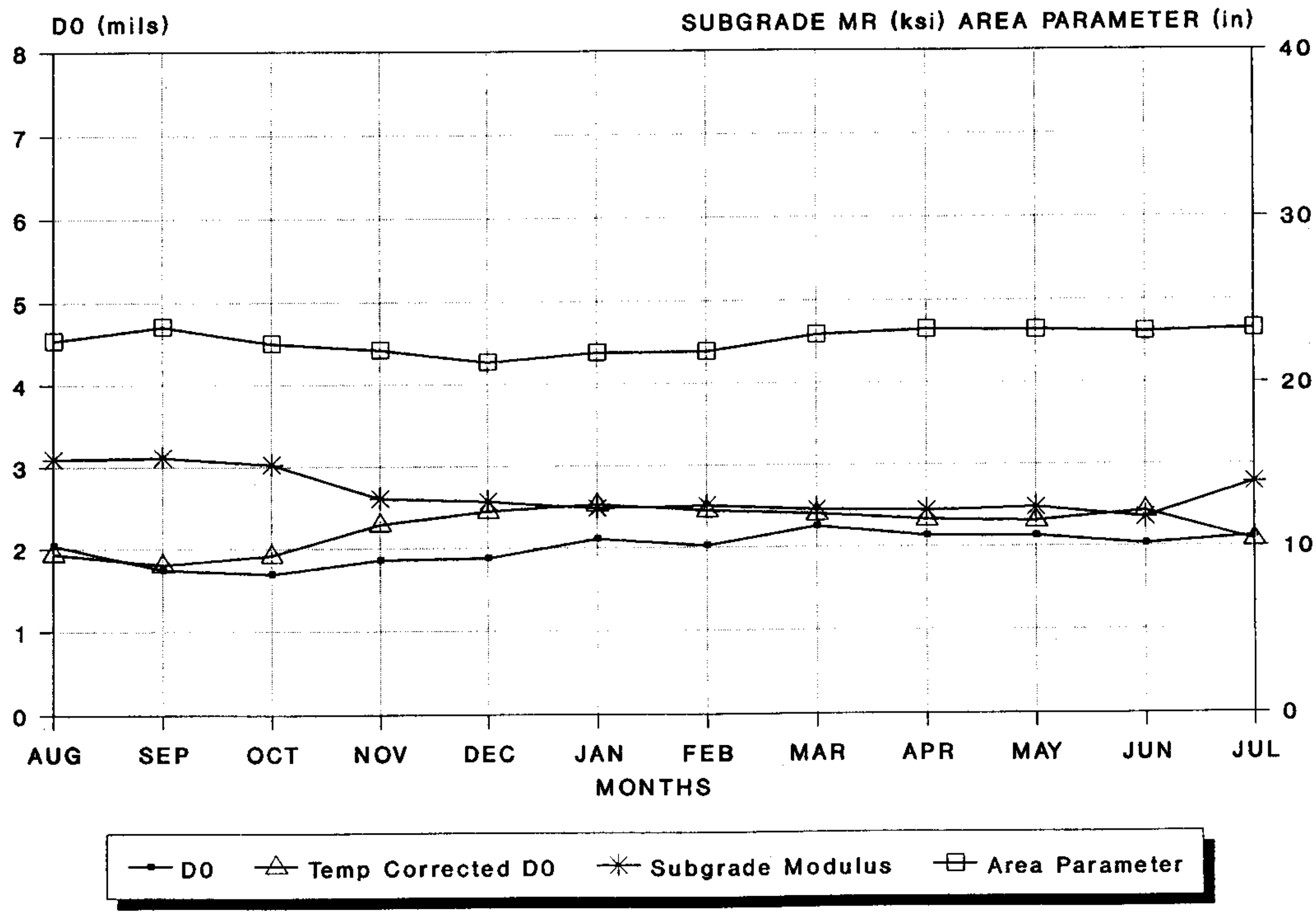
Test Location	Original Case Analyzed	Load +30 lb	Load -30 lb	AC Thickness + 0.5 in	AC Thickness - 0.5 in	Base Thickness + 0.5 in	Base Thickness - 0.5 in	Deflection 1.02% D0	Deflection 98% D0
Pavement Modulus (psi)									
1	200,000	235,731	200,000	307,330	601,514	556,510	200,000	200,000	265,057
2	440,053	482,300	399,590	409,852	468,094	485,840	394,361	370,635	200,000
3	200,000	200,000	200,000	200,000	1,000,000	200,000	200,000	200,000	275,076
4	254,800	333,745	200,000	200,000	200,000	200,000	200,000	200,000	772,113
5	1,000,000	1,000,000	1,000,000	771,840	1,000,000	1,000,000	1,000,000	925,713	1,000,000
6	200,000	200,000	200,000	200,000	713,361	200,000	200,000	200,000	1,000,000
7	281,513	308,523	255,586	277,822	614,567	317,096	200,000	200,000	1,000,000
8	453,863	497,408	412,025	407,954	724,268	499,697	407,502	393,062	1,000,000
9	837,761	985,301	757,517	642,726	1,000,000	917,068	733,107	697,792	333,054
10	655,031	780,309	600,983	523,604	771,596	723,183	656,863	482,542	758,430
Absolute Percent Difference in Error									
1	10.6	10.7	10.6	13.2	18.8	15.2	10.7	11.2	7.0
2	4.1	3.9	4.3	4.0	3.5	5.4	2.6	2.7	24.2
3	16.4	16.3	16.5	16.0	25.4	15.4	17.6	17.8	8.6
4	8.4	8.1	8.5	6.9	9.9	5.8	9.5	9.9	13.2
5	12.1	12.3	12.1	11.9	12.7	12.6	12.0	13.3	20.8
6	60.9	64.1	58.9	55.4	58.5	56.9	64.9	59.0	43.3
7	9.0	9.0	9.5	9.1	8.5	8.1	7.2	7.7	32.6
8	9.2	9.2	9.1	8.1	6.8	9.3	8.7	8.0	17.6
9	11.9	12.2	11.8	11.5	12.0	12.3	11.0	12.5	3.1
10	6.8	7.1	6.8	7.0	6.3	7.2	6.4	7.5	9.4
Average Percent Difference in Error									
	14.94	15.29	14.81	14.31	16.24	14.82	15.06	14.96	17.98

APPENDIX D

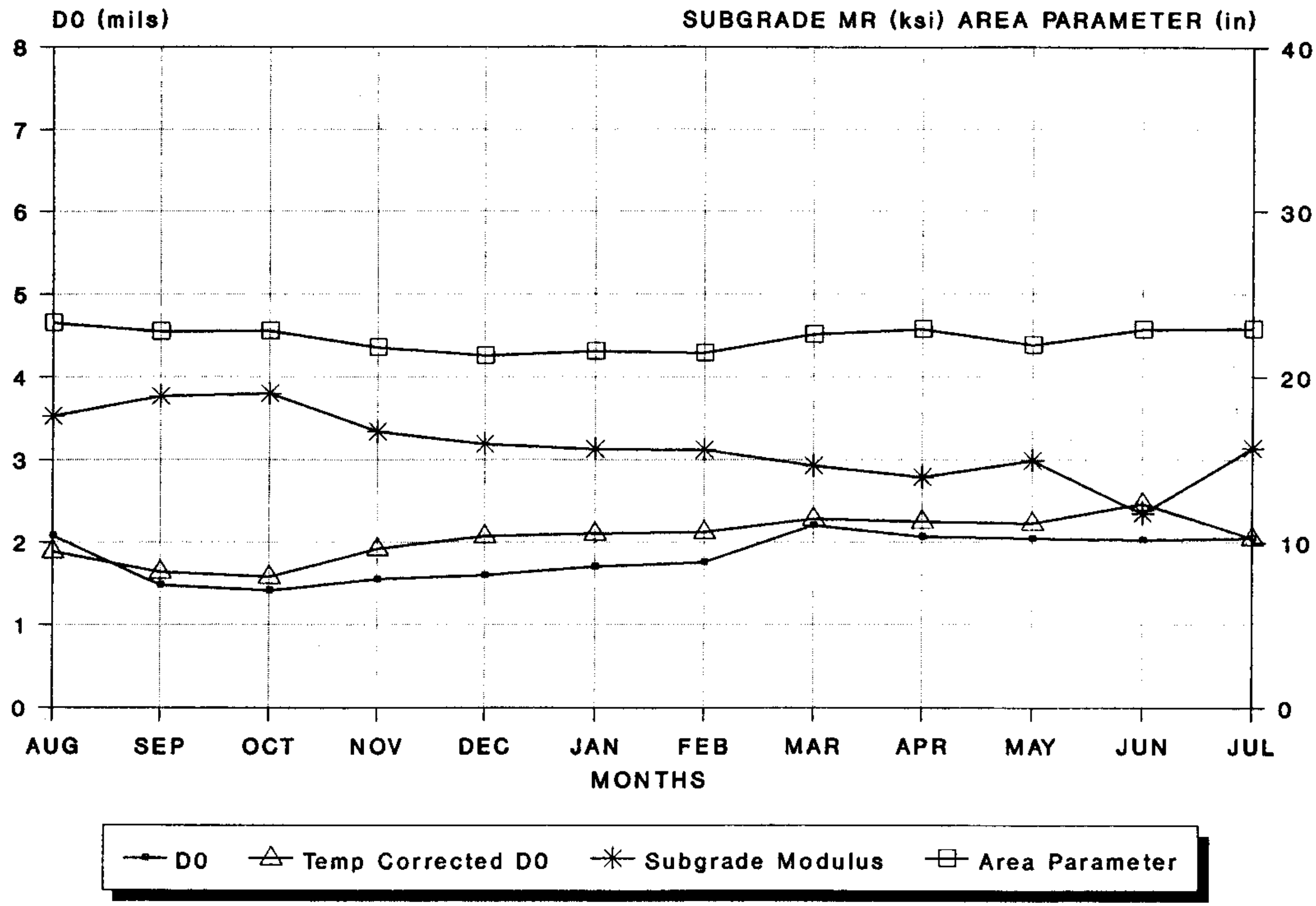
D1. CLARK COUNTY
TEST SECTION 01



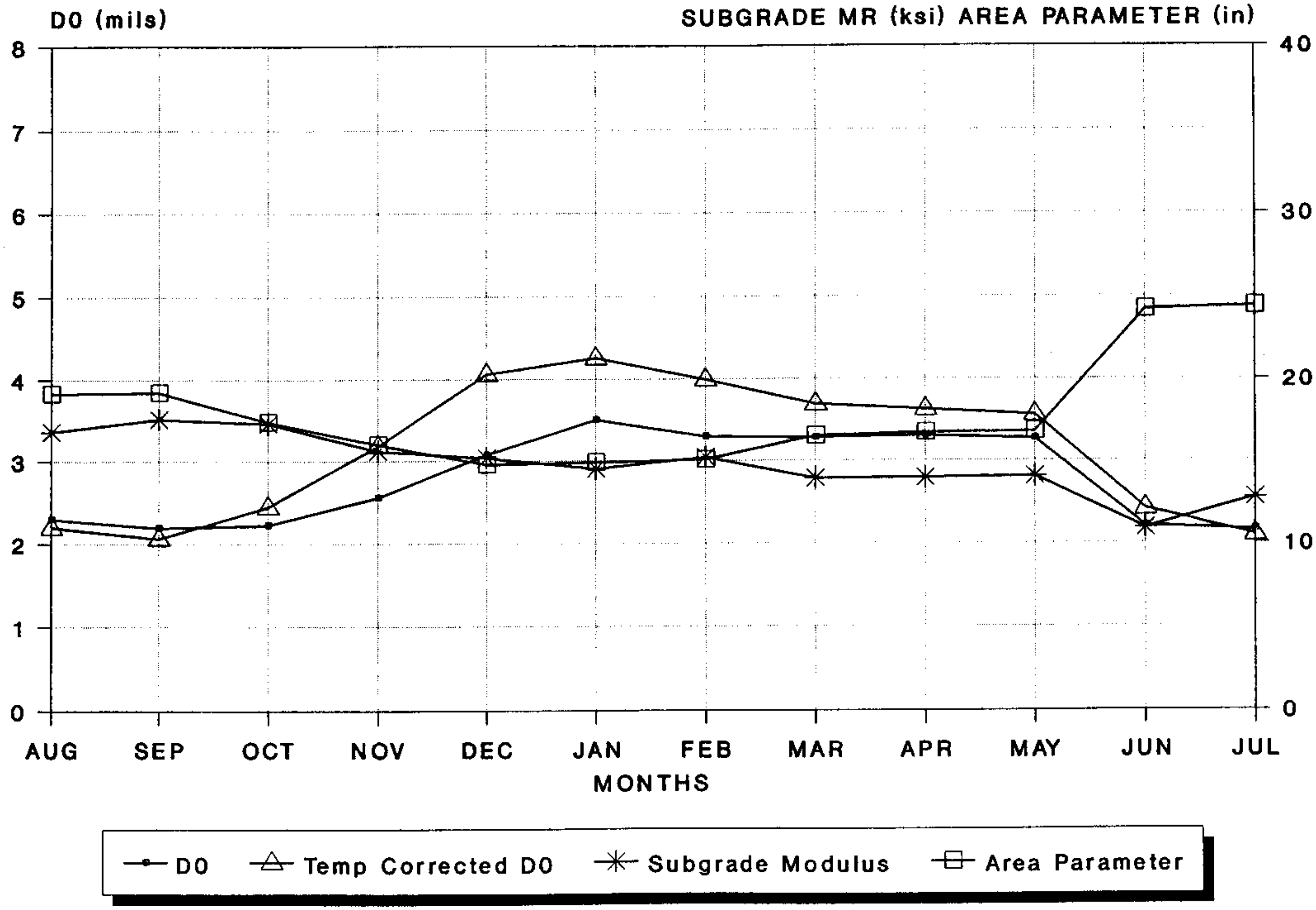
D2. CLARK COUNTY
TEST SECTION 02



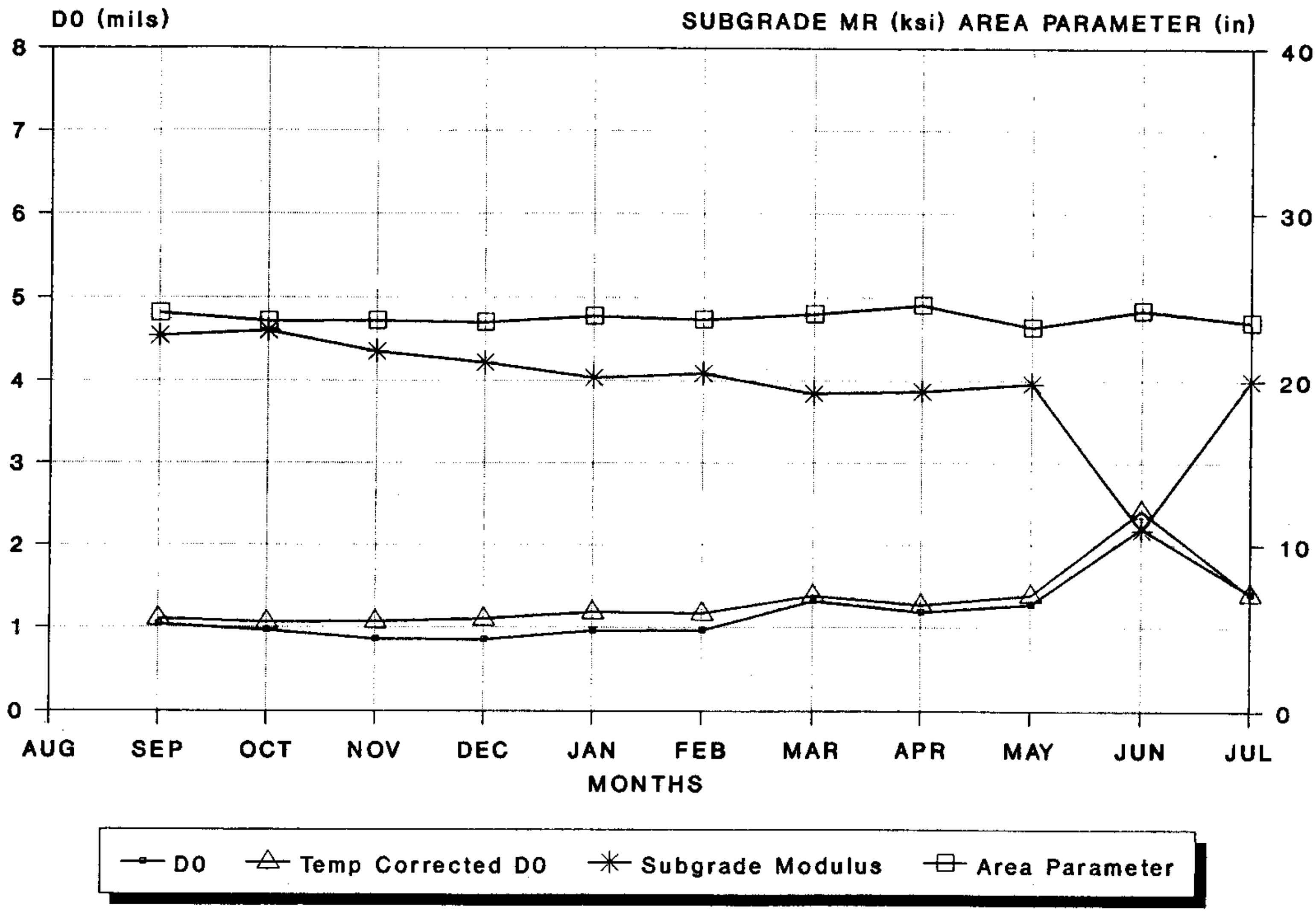
D3. CLARK COUNTY
TEST SECTION 03



D4. CLARK COUNTY
TEST SECTION 04

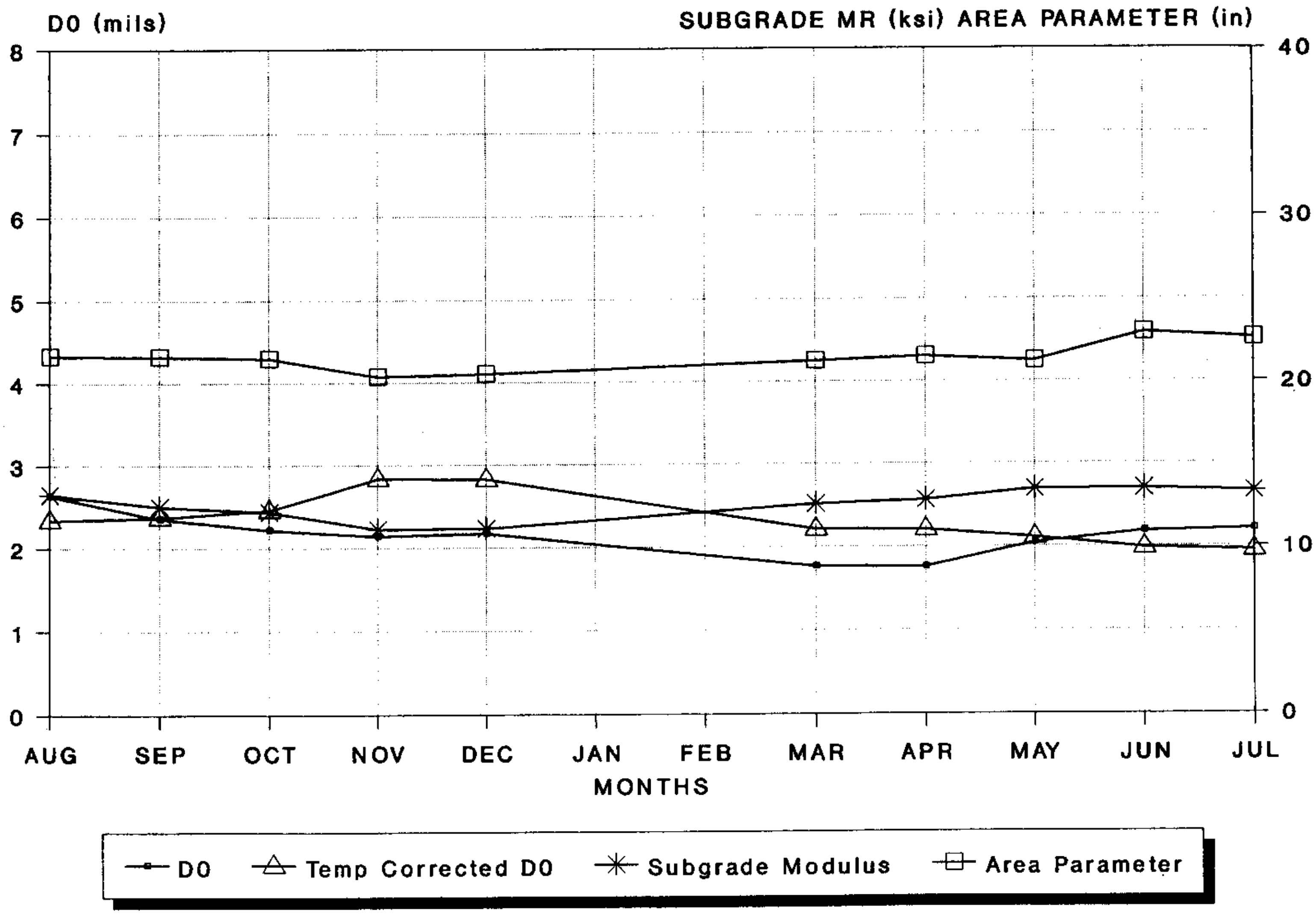


D5. CLARK COUNTY
TEST SECTION 05



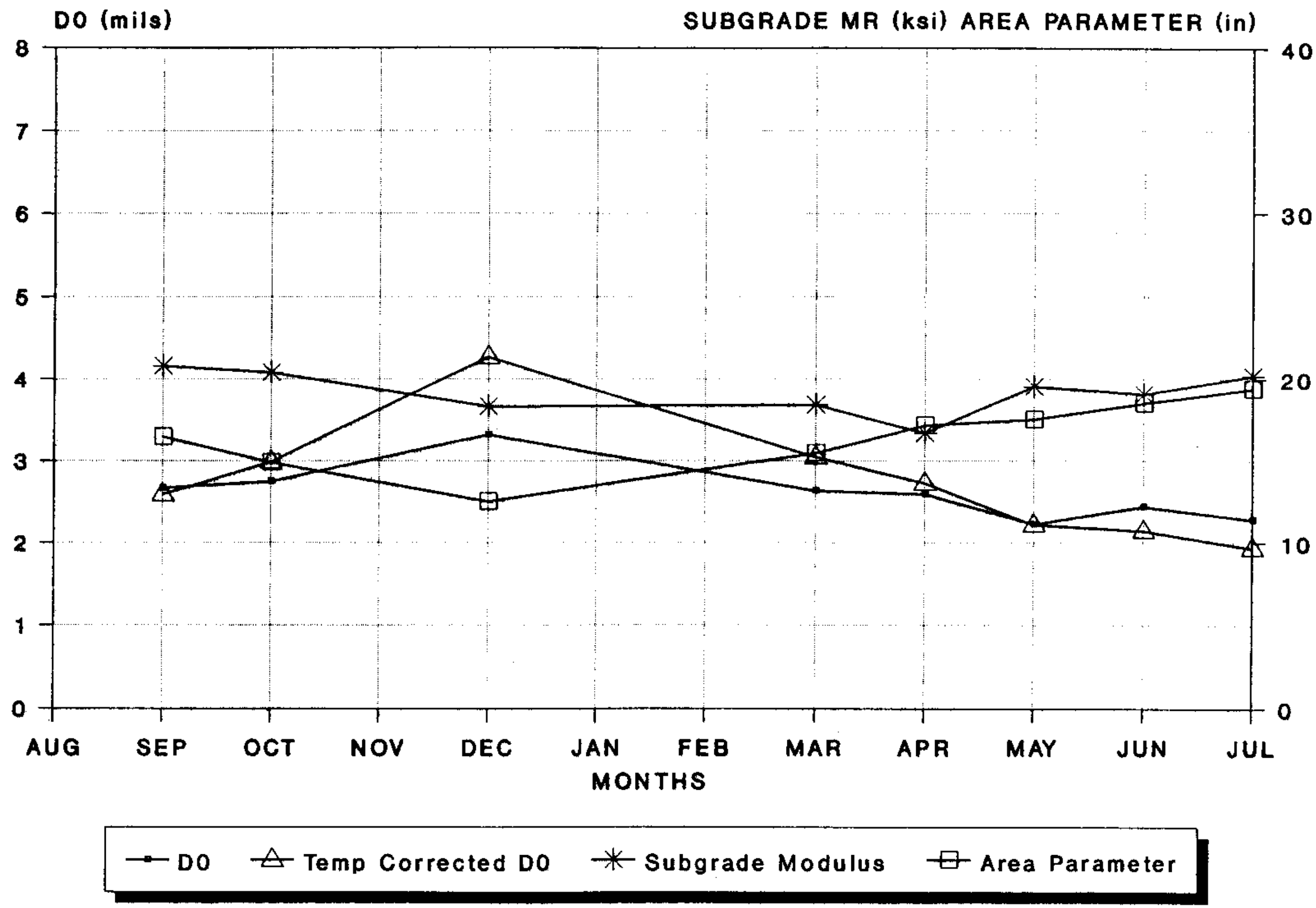
No data for AUG

D6. FRANKLIN COUNTY
TEST SECTION 01



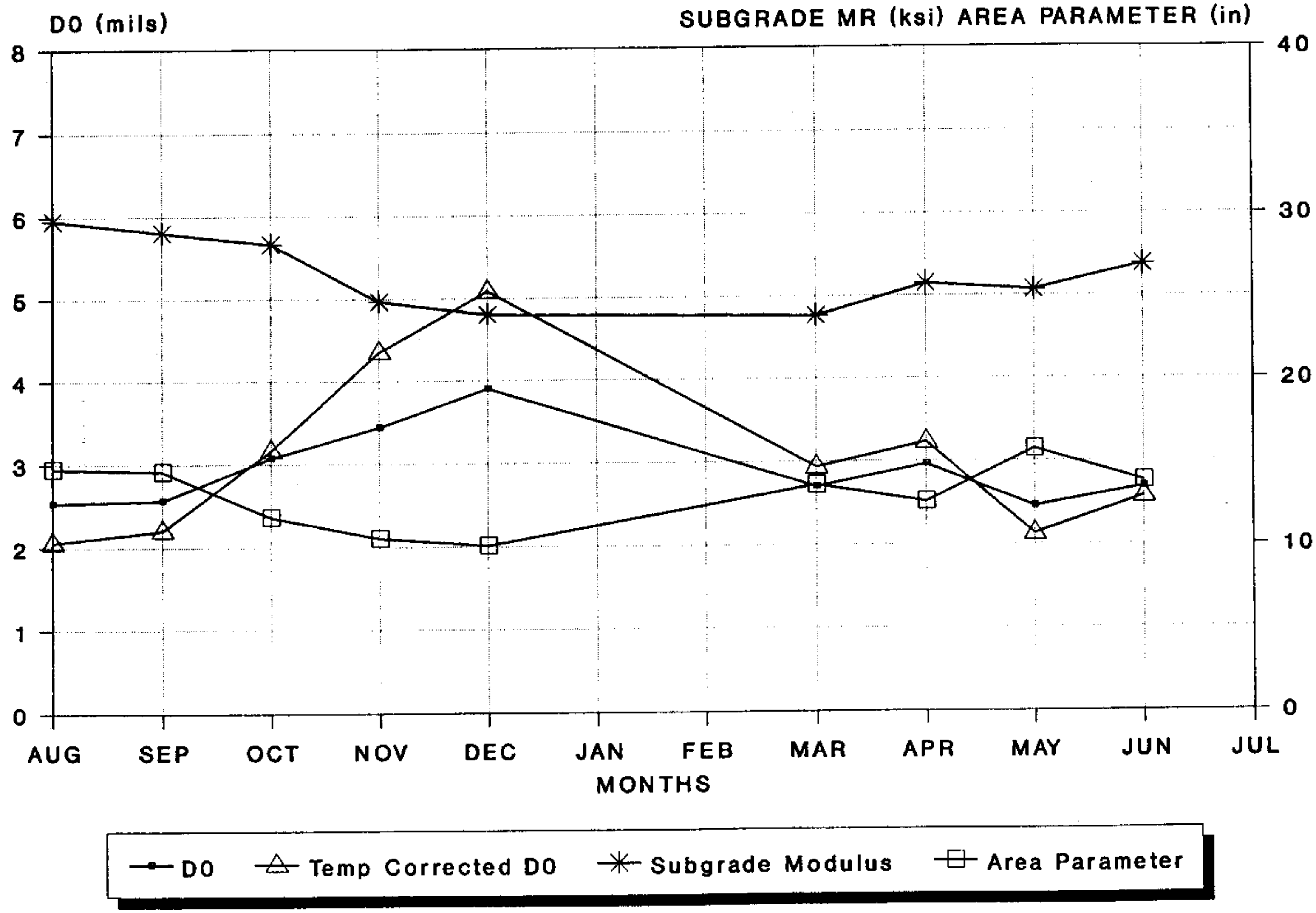
No data for JAN-FEB

D7. FRANKLIN COUNTY
TEST SECTION 02



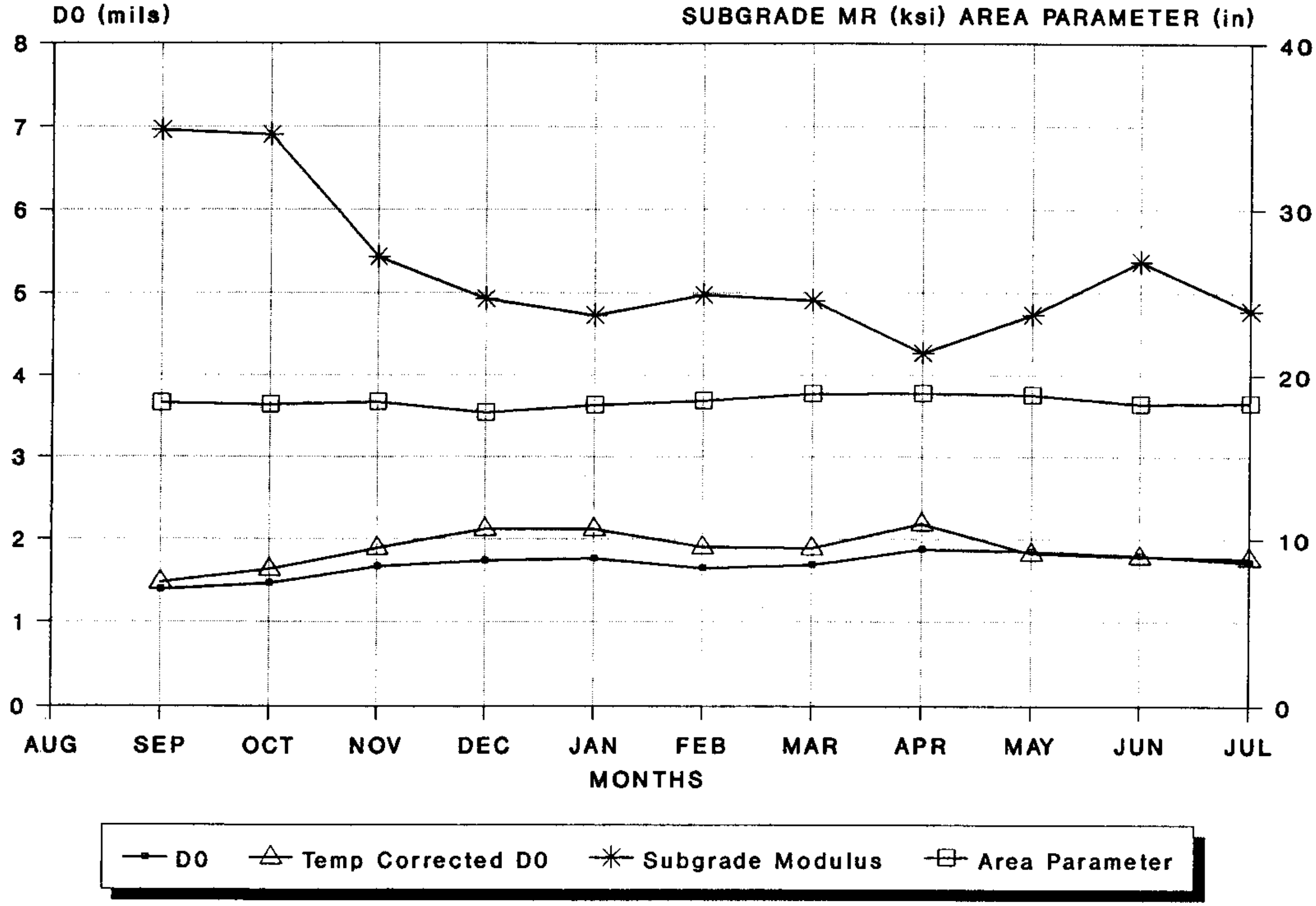
No data for AUG, NOV, JAN-FEB

D8. FRANKLIN COUNTY
TEST SECTION 03



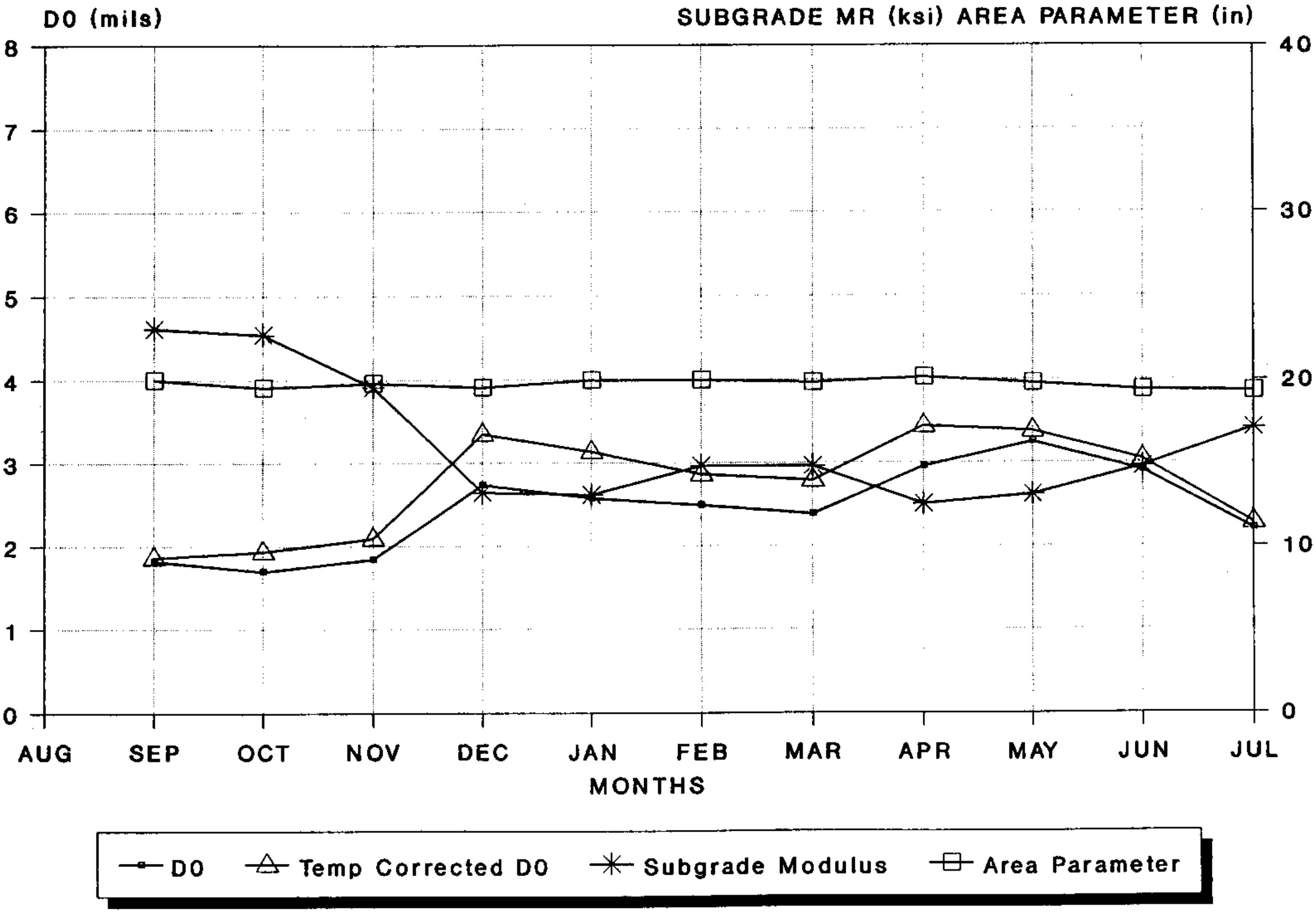
No data for JAN-FEB, JUL

D9. PIERCE COUNTY
TEST SECTION 01



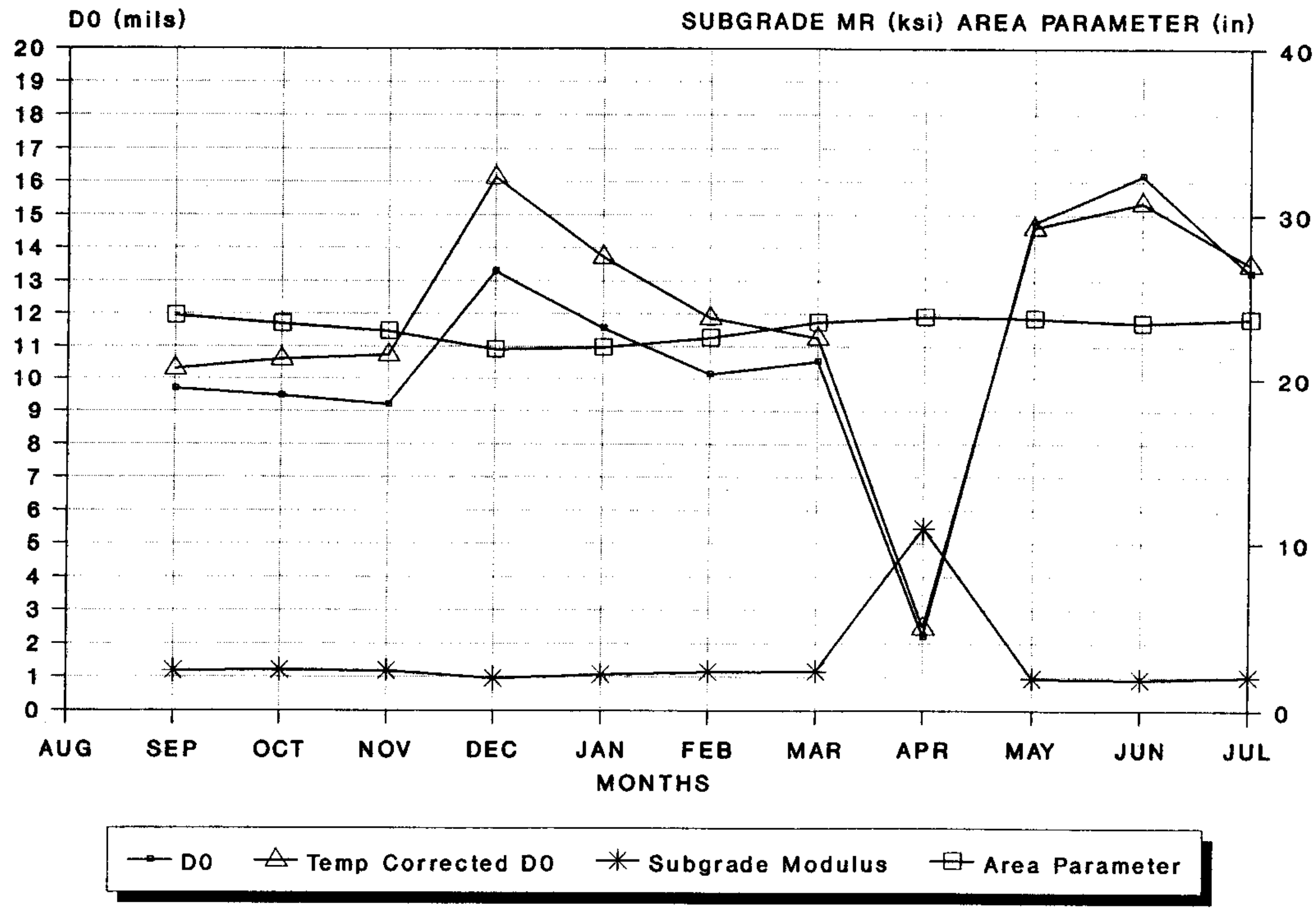
No data for AUG

D10. PIERCE COUNTY
TEST SECTION 02



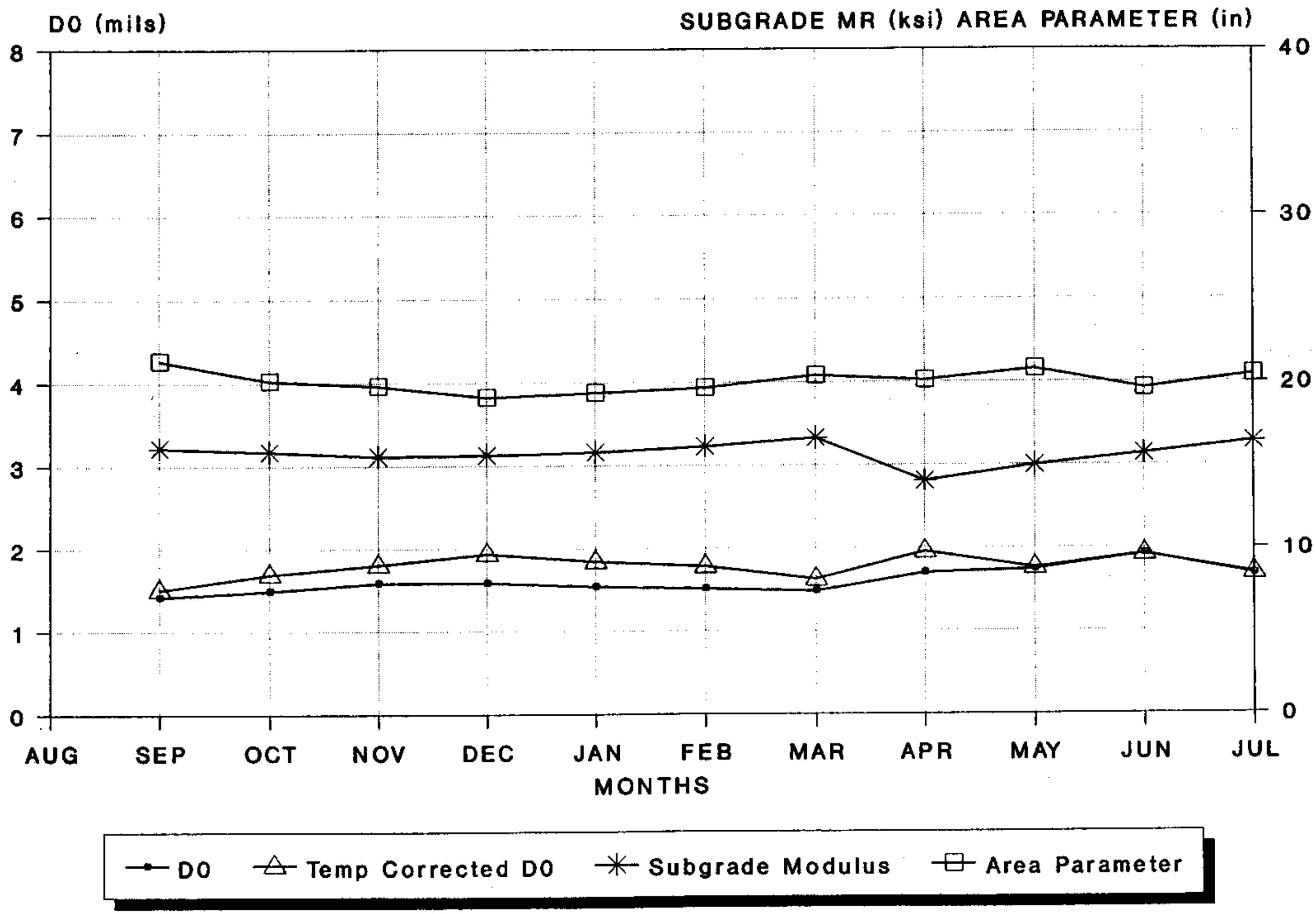
No data for AUG

D11. PIERCE COUNTY
TEST SECTION 04



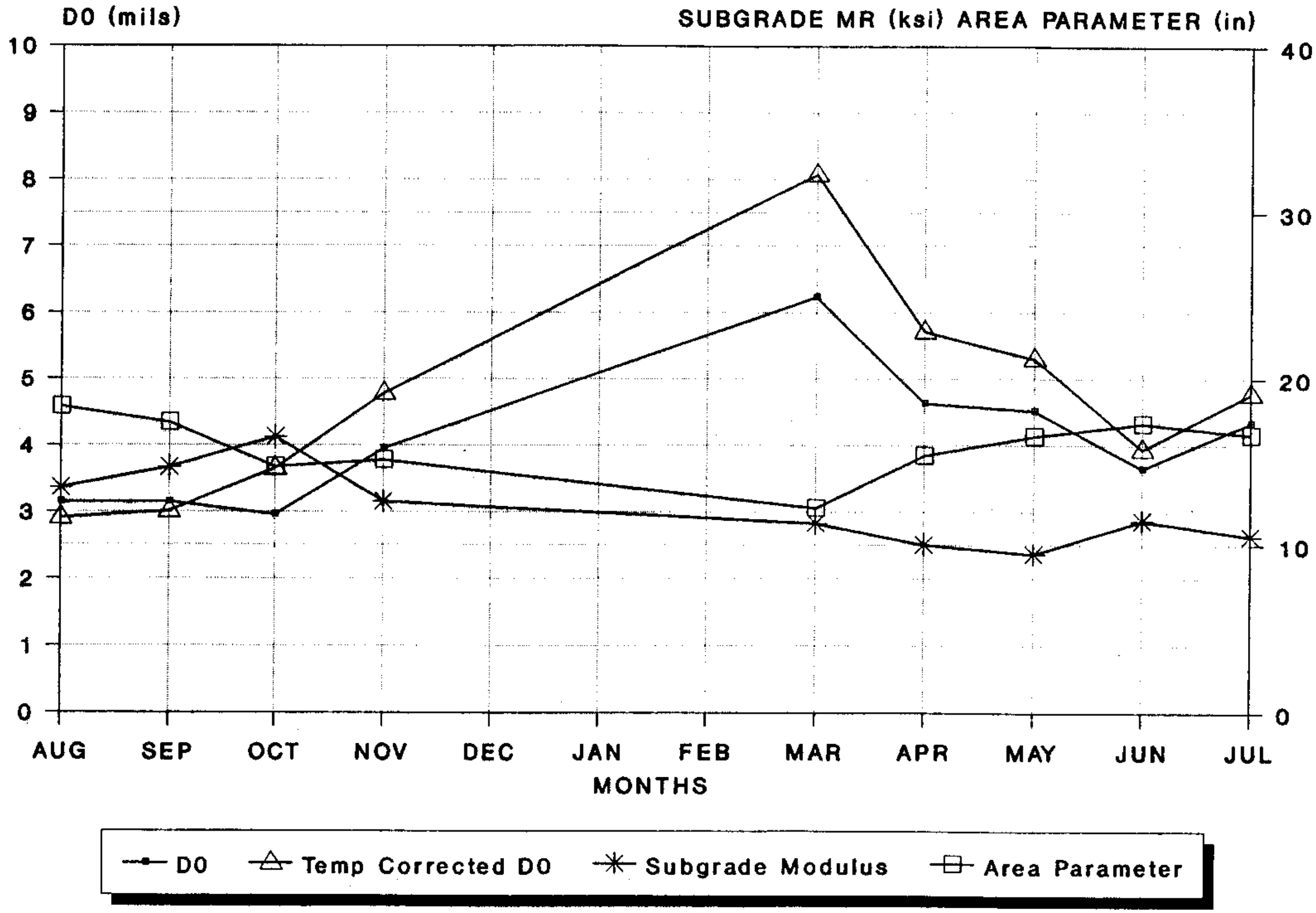
No data for AUG

D12. PIERCE COUNTY
TEST SECTION 05



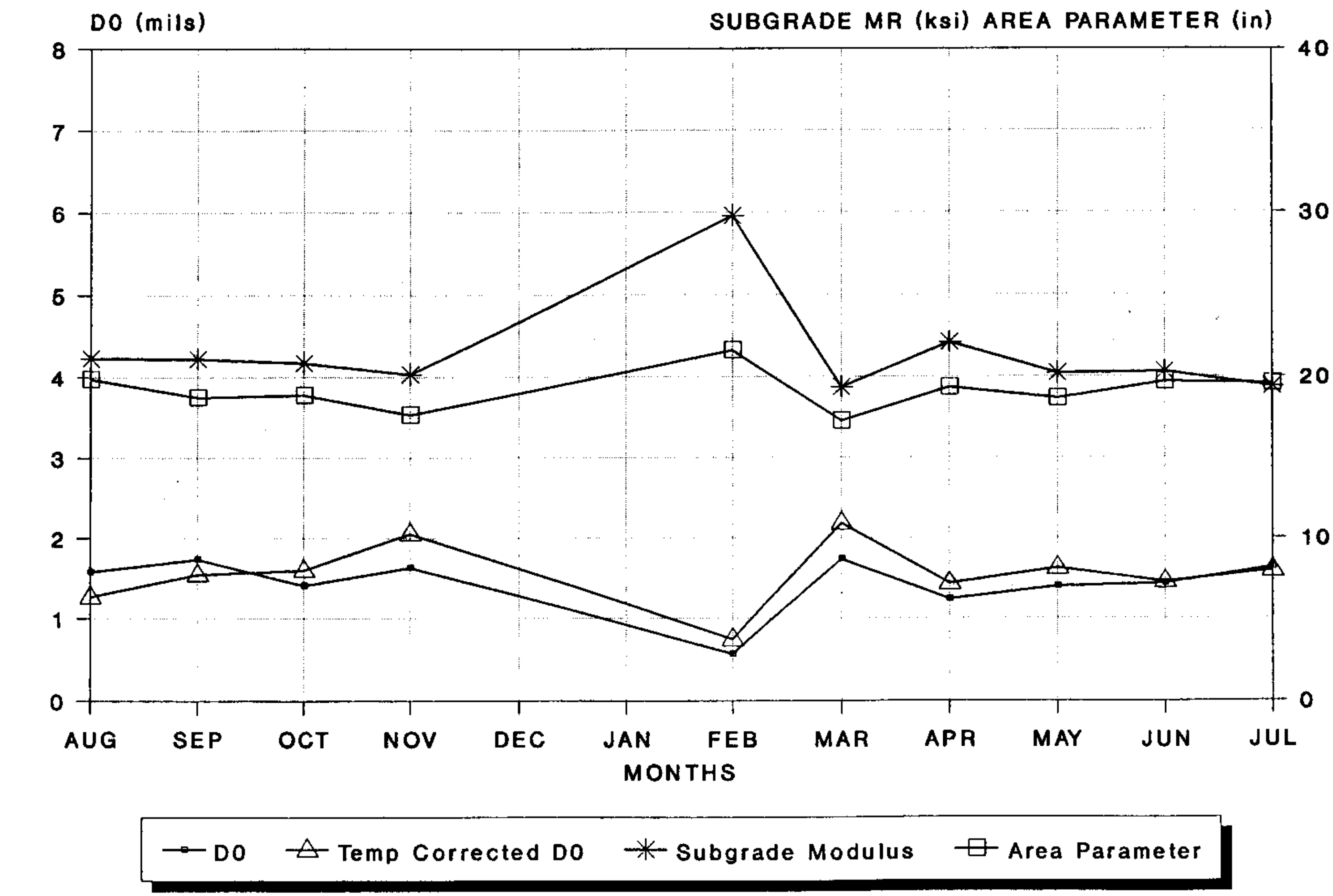
No data for AUG

D13. SPOKANE COUNTY
TEST SECTION 01



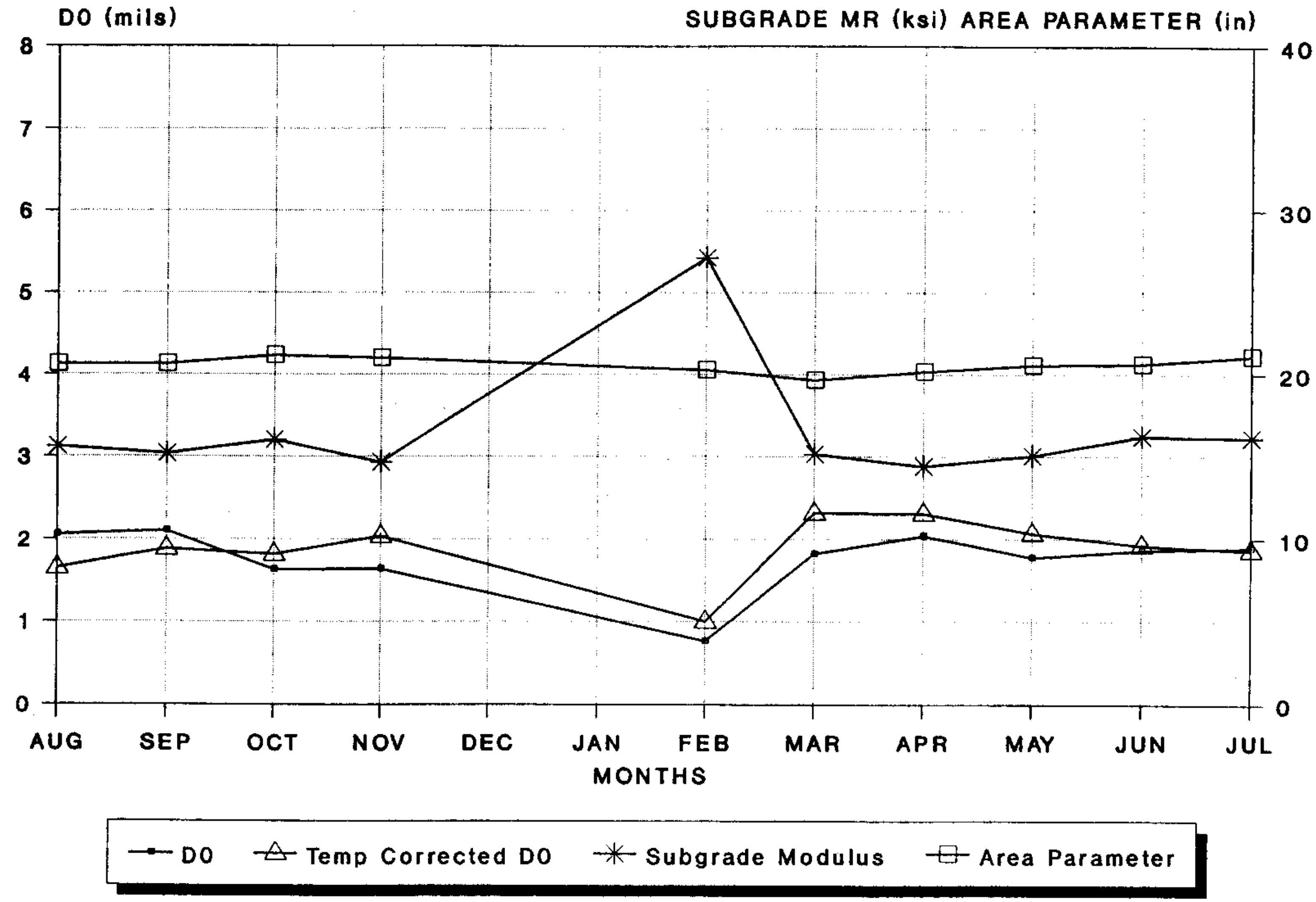
No data for DEC-FEB

D14. SPOKANE COUNTY
TEST SECTION 02



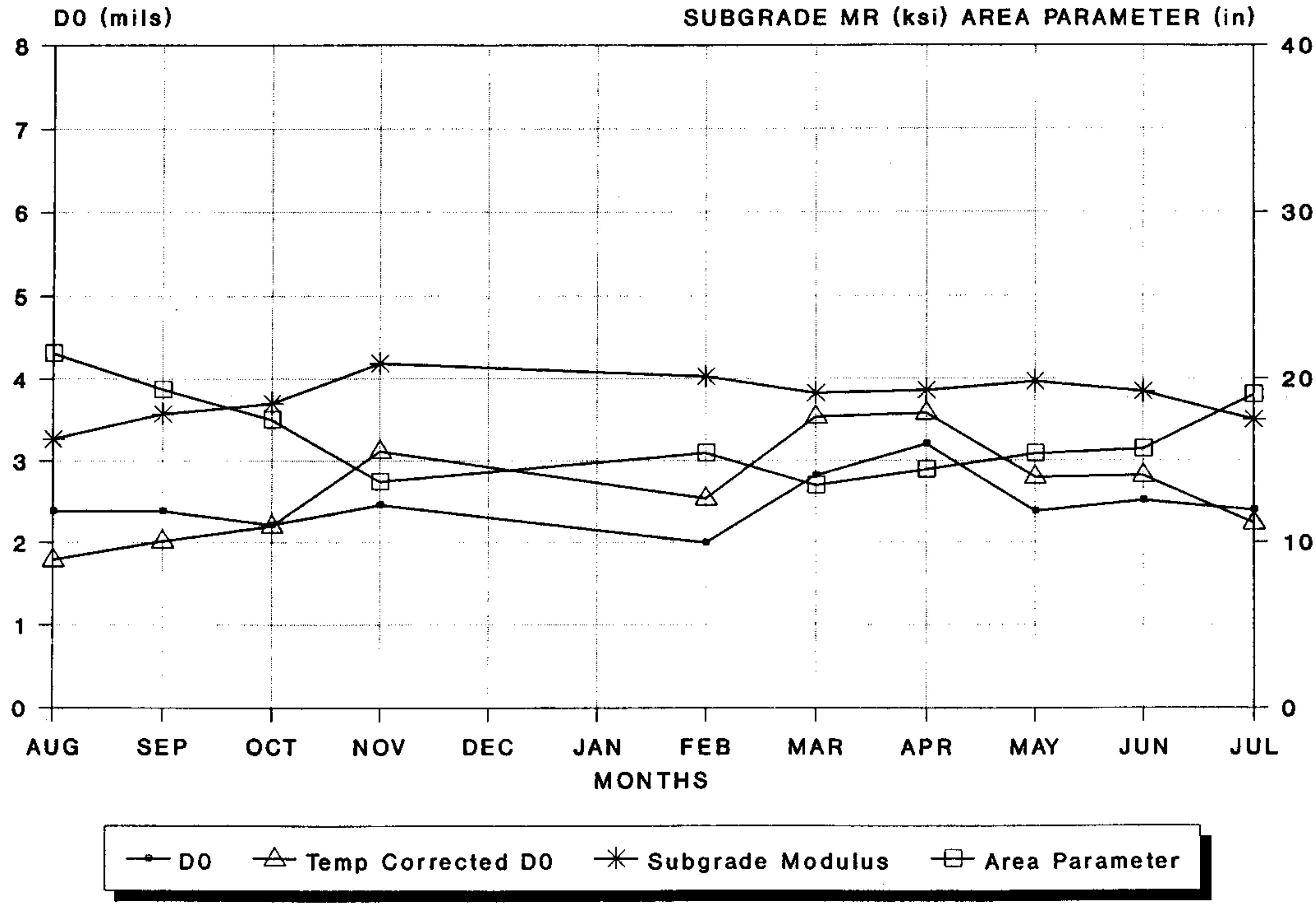
No data for DEC-JAN

D15. SPOKANE COUNTY
TEST SECTION 03



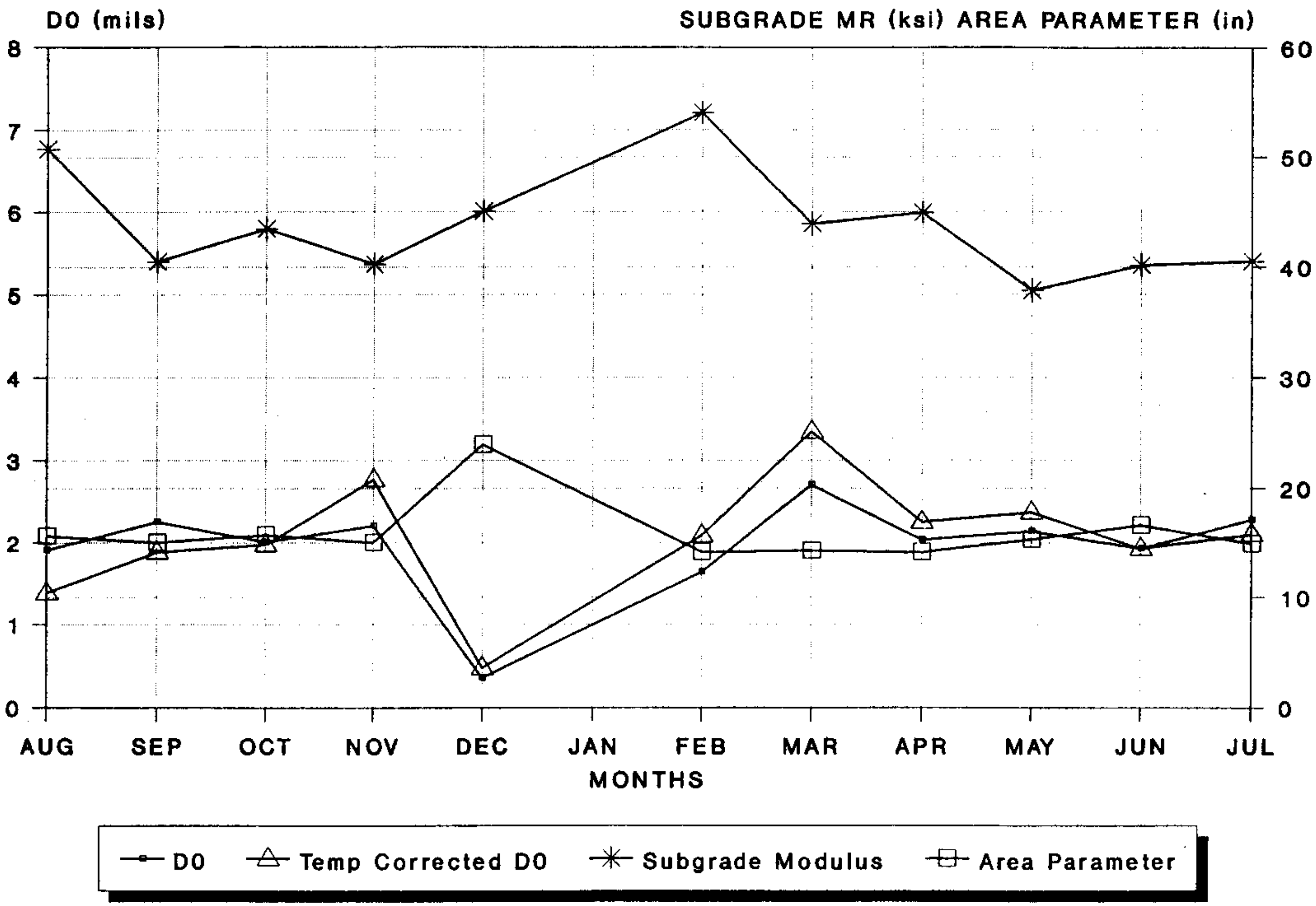
No data for DEC-JAN

D16. SPOKANE COUNTY
TEST SECTION 04



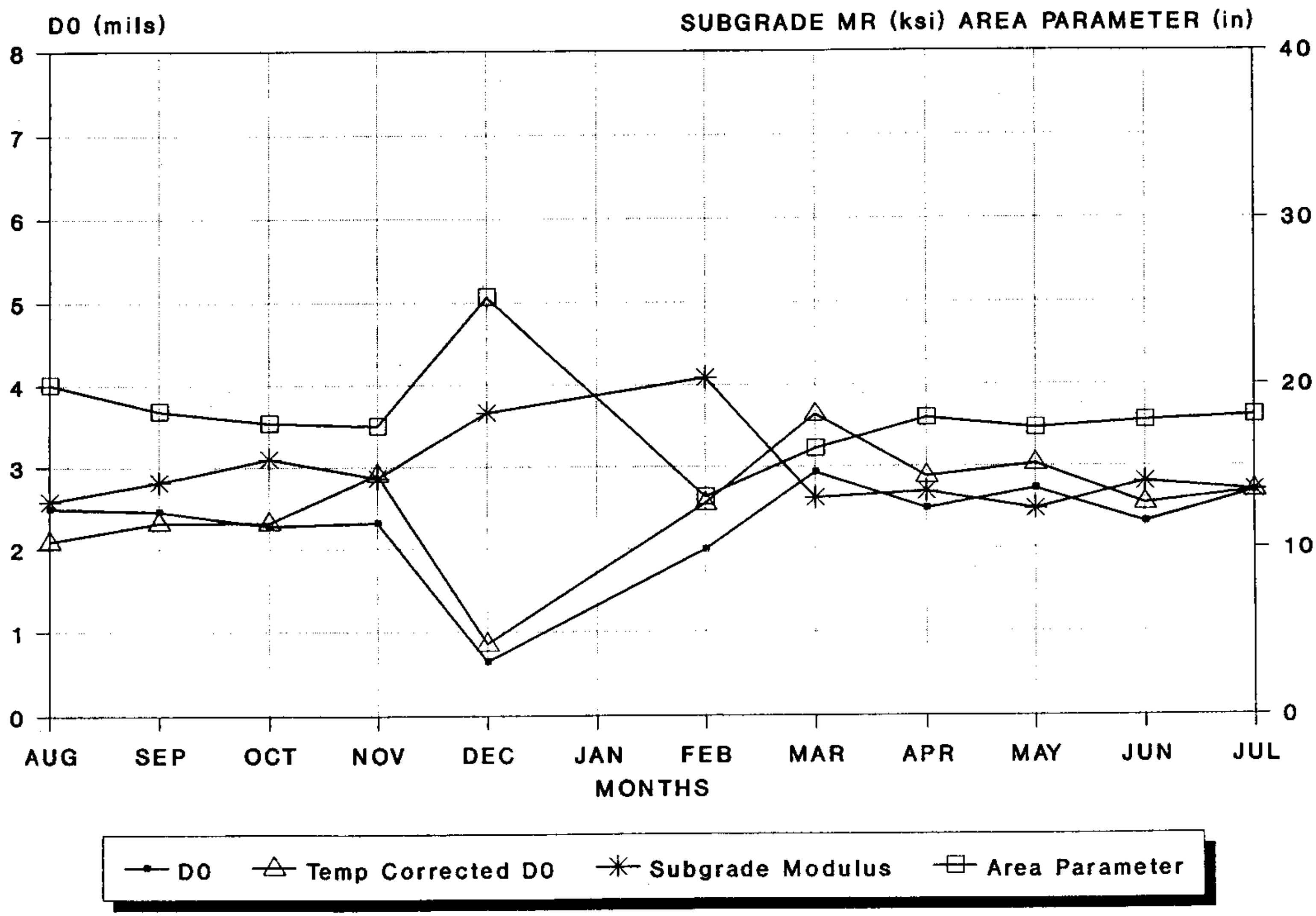
No data for DEC-JAN

D17. SPOKANE COUNTY
TEST SECTION 05



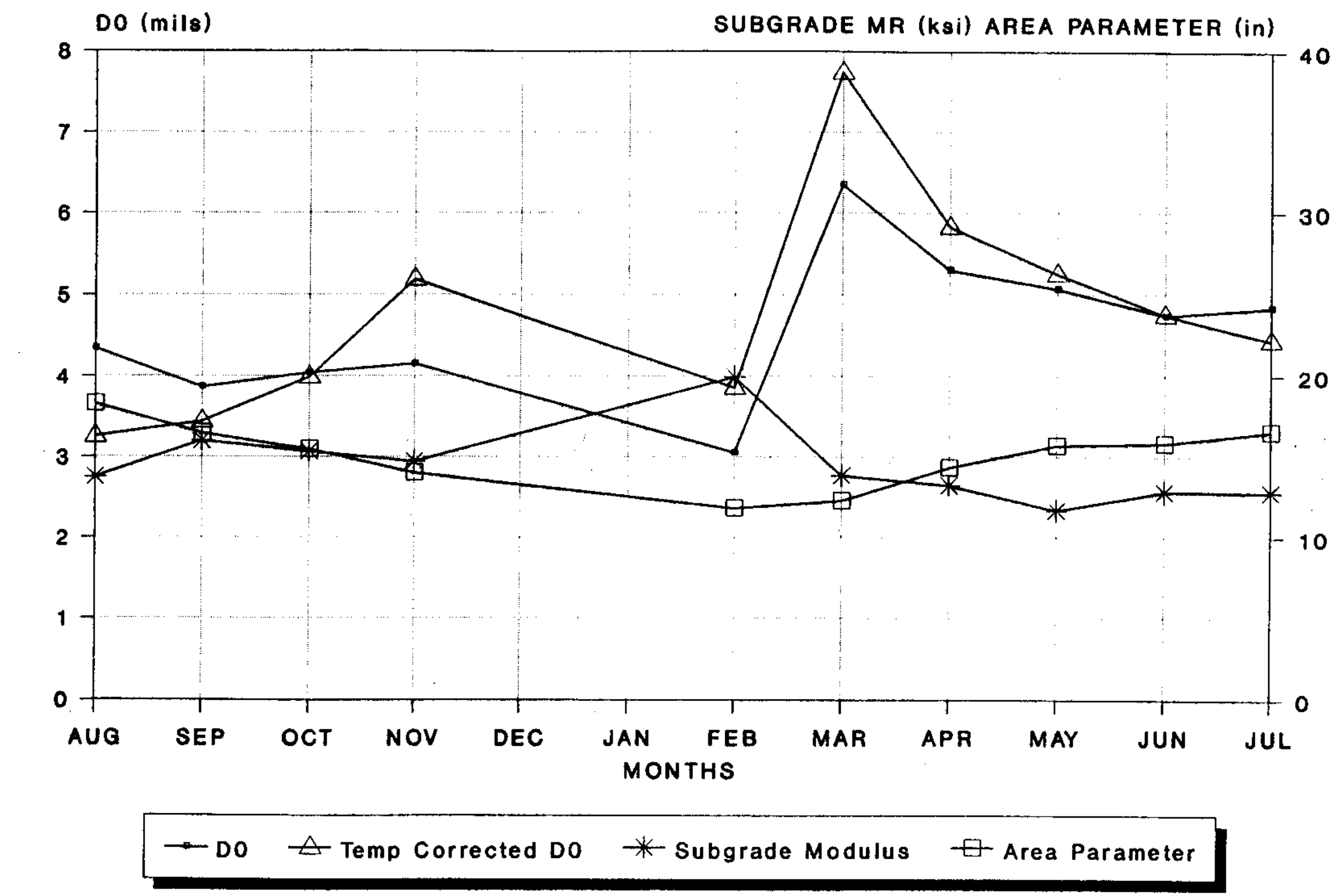
No data for JAN

D18. SPOKANE COUNTY
TEST SECTION 06



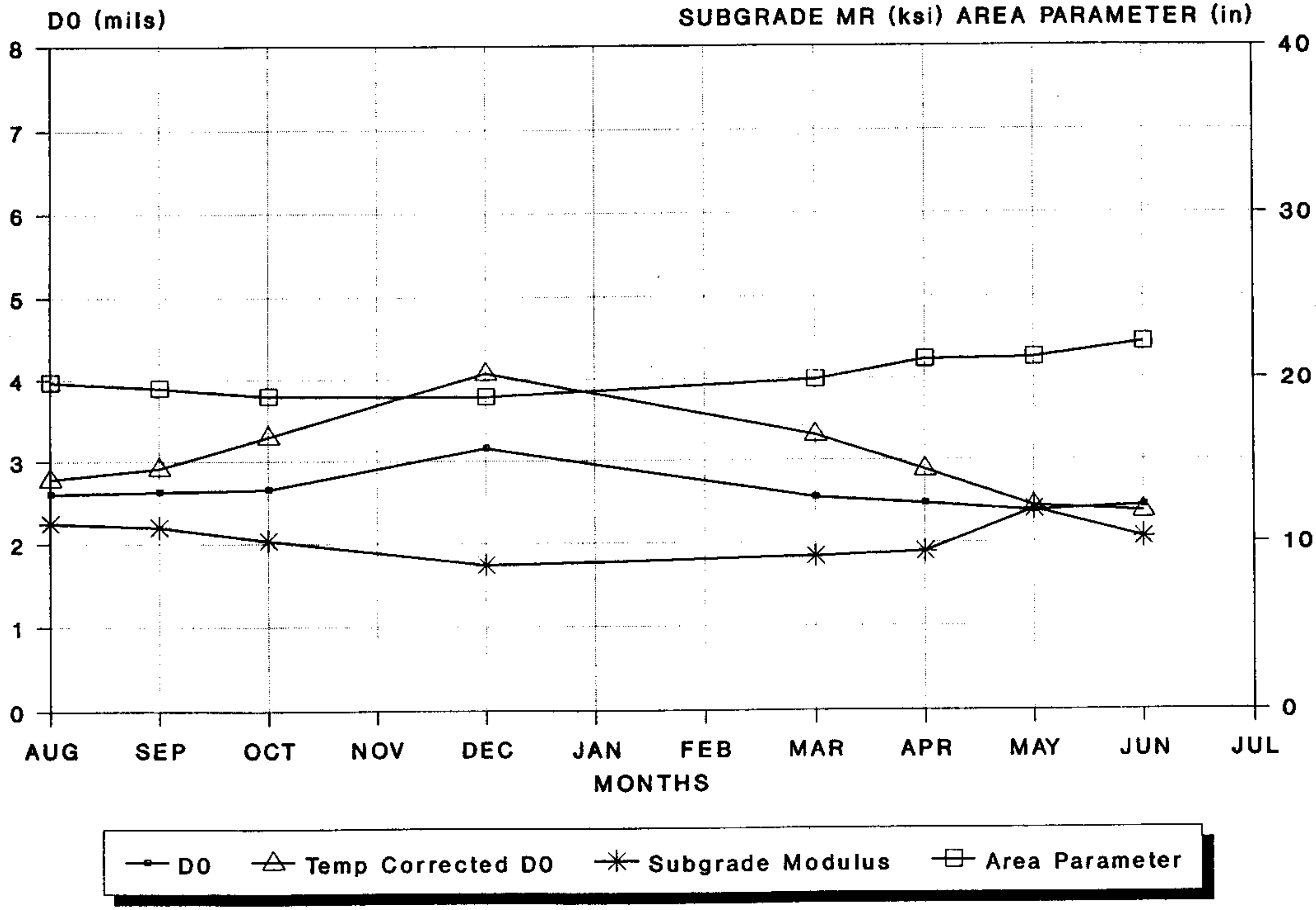
No data for JAN

D19. SPOKANE COUNTY
TEST SECTION 07



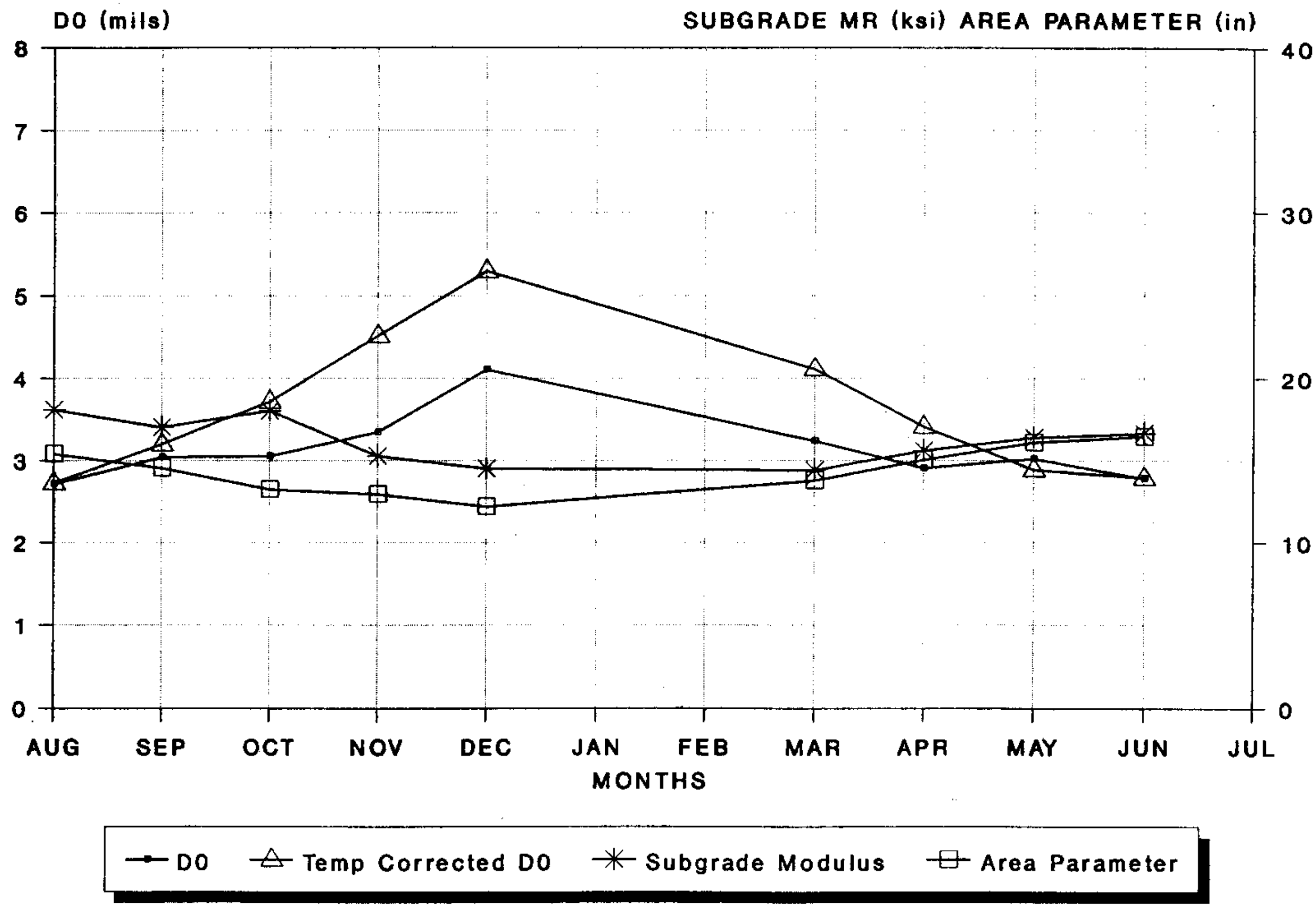
No data for DEC-JAN

D20. WALLA WALLA COUNTY
TEST SECTION 01



No data for NOV, JAN-FEB, JUL

D21. WALLA WALLA COUNTY
TEST SECTION 02



No data for JAN-FEB, JUL

TABLE D1
SEASONAL VARIATION IN MAXIMUM DEFLECTION

Test Section	Minimum Deflection (mils)	Maximum Deflection (mils)	Percent Difference[1]
CL01	1.95 (OCT)	2.29 (AUG)	17
CL02	1.69 (OCT)	2.25 (MAR)	33
CL03	1.41 (OCT)	2.21 (MAR)	57
CL04	2.02 (SEP)	3.50 (JAN)	73
CL05[2]	0.85 (DEC)	2.21 (JUN)	160
FR01[3]	1.76 (MAR)	2.64 (AUG)	50
FR02[3]	2.23 (MAY)	3.32 (DEC)	49
FR03[4]	2.46 (MAY)	3.90 (DEC)	59
PI01	1.39 (SEP)	1.88 (APR)	35
PI02	1.70 (OCT)	3.25 (MAY)	173
PI04[5]	9.21 (APR)	16.18 (JUN)	76
PI05[5]	1.42 (SEP)	1.92 (JUN)	35
SP01[6]	2.96 (OCT)	6.23 (MAR)	110
SP02[7]	1.23 (APR)	1.74 (SEP,MAR)	41
SP03[7]	1.63 (OCT)	2.10 (SEP)	29
SP04[7]	2.21 (OCT)	3.20 (APR)	45
SP05[7]	1.91 (AUG)	2.70 (MAR)	41
SP06[7]	2.28 (OCT)	2.93 (MAR)	29
SP07[6]	3.86 (SEP)	6.34 (MAR)	64
WA01[4]	2.38 (MAY)	3.15 (DEC)	32
WA02[4]	2.72 (AUG)	4.10 (DEC)	51
WH01[8]	1.62 (SEP)	3.17 (OCT)	96
WH02[8]	1.09 (DEC)	2.14 (FEB)	96
WH03[8]	2.19 (SEP)	2.91 (MAR,APR)	33
WH04[8]	1.07 (MAR)	3.56 (NOV)	233
WH05[8]	1.09 (MAR)	3.56 (NOV)	221

Notes:

[1]Percent difference is calculated as follows: $\frac{\text{maximum-minimum}}{\text{minimum}} \times 100$

[2]No data for the month of August.

[3]No data for the months of January and February.

[4]No data for the months of January, February and July.

[5]Values for April omitted.

[6]No data for the months of December and January. Data for February omitted due to frozen ground conditions.

[7]No data for the month of January. Data for December and February omitted due to frozen ground conditions.

[8]No data for the months of August and May. Data for January omitted due to frozen ground conditions.

TABLE D2
SEASONAL VARIATION IN SUBGRADE RESILIENT MODULUS

Test Section	Minimum Subgrade Resilient Modulus (ksi)	Maximum Subgrade Resilient Modulus (ksi)	Percent Difference[1]
CL01	10.91 (MAR)	13.72 (AUG)	26
CL02	11.75 (JUN)	15.57 (SEP)	33
CL03	11.75 (JUN)	18.99 (OCT)	62
CL04	10.91 (JUN)	17.56 (SEP)	61
CL05[2]	10.91 (JUN)	23.03 (OCT)	111
FR01[3]	11.14 (NOV)	13.48 (JUN)	21
FR02[3]	16.70 (APR)	20.81 (SEP)	25
FR03[4]	23.82 (DEC)	29.76 (MAR,MAY)	25
PI01	21.34 (MAR)	34.79 (SEP)	63
PI02	12.52 (APR)	23.07 (SEP)	84
PI04[5]	1.85 (JUN)	2.40 (OCT)	30
PI05[5]	14.05 (APR)	16.63 (MAR)	18
SP01[6]	9.46 (MAY)	16.48 (OCT)	74
SP02[7]	19.34 (MAR)	22.12 (APR)	14
SP03[7]	14.64 (MAY)	16.18 (JUN)	11
SP04[7]	16.34 (AUG)	20.94 (NOV)	28
SP05[7]	37.83 (MAY)	50.74 (AUG)	34
SP06[7]	12.41 (MAY)	14.31 (NOV)	15
SP07[6]	13.91 (MAR)	16.09 (NOV)	16
WA01[4]	8.67 (DEC)	12.00 (MAY)	38
WA02[4]	14.39 (MAR)	18.10 (AUG)	26
WH01[8]	12.26 (APR)	16.06 (SEP)	31
WH02[8]	10.66 (APR)	14.29 (DEC)	34
WH03[8]	25.22 (MAR)	32.50 (SEP)	29
WH04[8]	14.84 (APR)	21.21 (DEC)	43
WH05[8]	11.90 (MAR)	17.63 (DEC)	48

Notes:

[1]Percent difference is calculated as follows: $\frac{\text{maximum-minimum}}{\text{minimum}} \times 100$

[2]No data for the month of August.

[3]No data for the months of January and February.

[4]No data for the months of January, February and July.

[5]Values for April omitted.

[6]No data for the months of December and January. Data for February omitted due to frozen ground conditions.

[7]No data for the month of January. Data for December and February omitted due to frozen ground conditions.

[8]No data for the months of August and May. Data for January omitted due to frozen ground conditions.

TABLE D3
SEASONAL VARIATION IN AREA PARAMETER

Test Section	Minimum Value of Area Parameter (in^2)	Maximum Value of Area Parameter (in^2)	Percent Difference[1]
CL01	22.21 (AUG)	25.89 (DEC)	17
CL02	21.89 (AUG)	25.80 (JUN)	18
CL03	21.87 (AUG)	24.98 (DEC)	14
CL04	16.84 (JAN)	23.89 (JUL)	42
CL05[2]	23.35 (JUL)	27.50 (DEC)	18
FR01[3]	20.04 (AUG)	24.79 (APR)	24
FR02[3]	14.63 (DEC)	17.68 (APR)	21
FR03[4]	11.84 (DEC)	14.31 (MAR,MAY)	21
PI01	18.10 (JUN)	20.72 (APR)	21
PI02	19.64 (JUL)	22.58 (JAN)	15
PI04[5]	22.59 (JUN)	25.20 (NOV)	12
PI05[5]	19.54 (JUN)	22.12 (SEP)	13
SP01[6]	14.35 (MAR)	18.27 (MAY)	27
SP02[7]	17.34 (AUG)	21.21 (APR)	22
SP03[7]	18.02 (AUG)	24.04 (NOV)	33
SP04[7]	15.47 (APR)	18.16 (AUG,JUL)	17
SP05[7]	12.93 (AUG)	17.29 (NOV)	34
SP06[7]	17.70 (SEP)	20.07 (NOV)	13
SP07[6]	13.91 (MAR)	16.09 (NOV)	16
WA01[4]	20.62 (AUG)	23.35 (MAR)	13
WA02[4]	14.26 (DEC)	16.62 (APR)	17
WH01[8]	17.11 (NOV)	24.25 (MAR)	42
WH02[8]	15.71 (NOV)	28.88 (APR)	84
WH03[8]	12.65 (DEC,JUN)	13.35 (MAR)	6
WH04[8]	12.77 (NOV)	27.55 (APR)	116
WH05[8]	13.48 (NOV)	28.82 (MAR)	117

Notes:

[1]Percent difference is calculated as follows: $\frac{\text{maximum-minimum}}{\text{minimum}} \times 100$

[2]No data for the month of August.

[3]No data for the months of January and February.

[4]No data for the months of January, February and July.

[5]Values for April omitted.

[6]No data for the months of December and January. Data for February omitted due to frozen ground conditions.

[7]No data for the month of January. Data for December and February omitted due to frozen ground conditions.

[8]No data for the months of August and May. Data for January omitted due to frozen ground conditions.

TABLE D4
SEASONAL VARIATION IN MAXIMUM DEFLECTION WITH TEMPERATURE CORRECTION

Test Section	Minimum Deflection (mils)	Maximum Deflection (mils)	Percent Difference[1]
CL01	1.86 (AUG)	2.68 (DEC)	44
CL02	1.80 (SEP)	2.53 (JAN)	40
CL03	1.58 (OCT)	2.28 (MAR)	44
CL04	2.06 (SEP)	4.26 (JAN)	107
CL05[2]	1.06 (OCT)	2.42 (JUN)	128
FR01[3]	1.95 (JUL)	2.84 (NOV)	46
FR02[3]	1.94 (JUL)	4.27 (DEC)	120
FR03[4]	2.06 (AUG)	5.08 (DEC)	147
PI01	1.47 (SEP)	2.18 (APR)	48
PI02	1.86 (SEP)	3.44 (APR)	85
PI04[5]	10.29 (SEP)	16.14 (DEC)	57
PI05[5]	1.51 (SEP)	1.96 (APR)	30
SP01[6]	2.91 (AUG)	8.08 (MAR)	178
SP02[7]	1.26 (AUG)	2.19 (MAR)	74
SP03[7]	1.65 (AUG,OCT)	2.32 (MAR)	41
SP04[7]	1.79 (AUG)	3.58 (APR)	100
SP05[7]	1.39 (AUG)	3.34 (MAR)	140
SP06[7]	2.08 (AUG)	3.63 (MAR)	74
SP07[6]	3.25 (AUG)	7.73 (MAR)	138
WA01[4]	2.37 (JUN)	4.07 (DEC)	72
WA02[4]	2.73 (AUG)	5.30 (DEC)	94
WH01[8]	–	–	
WH02[8]	–	–	
WH03[8]	–	–	
WH04[8]	–	–	
WH05[8]	–	–	

Notes:

[1]Percent difference is calculated as follows: $\frac{\text{maximum-minimum}}{\text{minimum}} \times 100$

[2]No data for the month of August.

[3]No data for the months of January and February.

[4]No data for the months of January, February and July.

[5]Values for April omitted.

[6]No data for the months of December and January. Data for February omitted due to frozen ground conditions.

[7]No data for the month of January. Data for December and February omitted due to frozen ground conditions.

[8]No pavement surface temperature data collected for Whatcom County.

TABLE D5
SEASONAL VARIATION IN AREA PARAMETER WITH TEMPERATURE CORRECTION

Test Section	Minimum Value of Area Parameter (in^2)	Maximum Value of Area Parameter (in^2)	Percent Difference[1]
CL01	21.97 (DEC)	25.20 (AUG)	15
CL02	21.35 (DEC)	23.28 (JUL)	9
CL03	21.30 (DEC)	23.29 (AUG)	9
CL04	14.77 (DEC)	24.40 (JUL)	65
CL05[2]	23.22 (MAY)	24.34 (APR)	5
FR01[3]	20.37 (NOV)	22.95 (JUN)	13
FR02[3]	12.52 (DEC)	19.42 (JUL)	55
FR03[4]	10.07 (DEC)[9]	15.69 (MAY)	56
PI01	17.69 (DEC)	18.87 (APR)	7
PI02	19.30 (JUL)	20.12 (APR)	4
PI04[5]	21.79 (DEC)	23.87 (SEP)	10
PI05[5]	19.13 (DEC)	21.36 (SEP)	12
SP01[6]	12.24 (MAR)	18.30 (AUG)	50
SP02[7]	17.26 (MAR)	19.87 (AUG)	15
SP03[7]	19.63 (MAR)	20.63 (AUG)	5
SP04[7]	13.50 (MAR)	21.55 (AUG)	60
SP05[7]	14.12 (APR)	16.59 (JUN)	17
SP06[7]	16.11 (MAR)	20.05 (AUG)	24
SP07[6]	12.30 (MAR)	18.27 (AUG)	48
WA01[4]	18.27 (NOV)	22.20 (JUN)	22
WA02[4]	12.95 (NOV)	16.45 (JUN)	27
WH01[8]	--	--	--
WH02[8]	--	--	--
WH03[8]	--	--	--
WH04[8]	--	--	--
WH05[8]	--	--	--

Notes:

[1]Percent difference is calculated as follows: $\frac{\text{maximum-minimum}}{\text{minimum}} \times 100$

[2]No data for the month of August.

[3]No data for the months of January and February.

[4]No data for the months of January, February and July.

[5]Values for April omitted.

[6]No data for the months of December and January. Data for February omitted due to frozen ground conditions.

[7]No data for the month of January. Data for December and February omitted due to frozen ground conditions.

[8]No pavement surface temperatur data collected for Whatcom County.

[9]Value for area parameter is outside of the lower bound limit of 11.1.

APPENDIX E

APPENDIX E

EXAMPLE OF ESTIMATING AVERAGE PAVEMENT TEMPERATURE

Deflection testing was performed on August 2, 1992.

The surface layer consists of 3.5 inches of AC

The pavement surface temperature = **89°F**
(obtained from the Road Rater)

Daily high and low temperatures

Date	High (°F)	Low (°F)
July 28, 1992	82	64
July 29, 1992	87	65
July 30, 1992	89	63
July 31, 1992	81	60
August 1, 1992	85	61

Mean 5-day air temperature = [(82+64)+(87+65)+(89+63)+(81+60)+(85+61)]/10

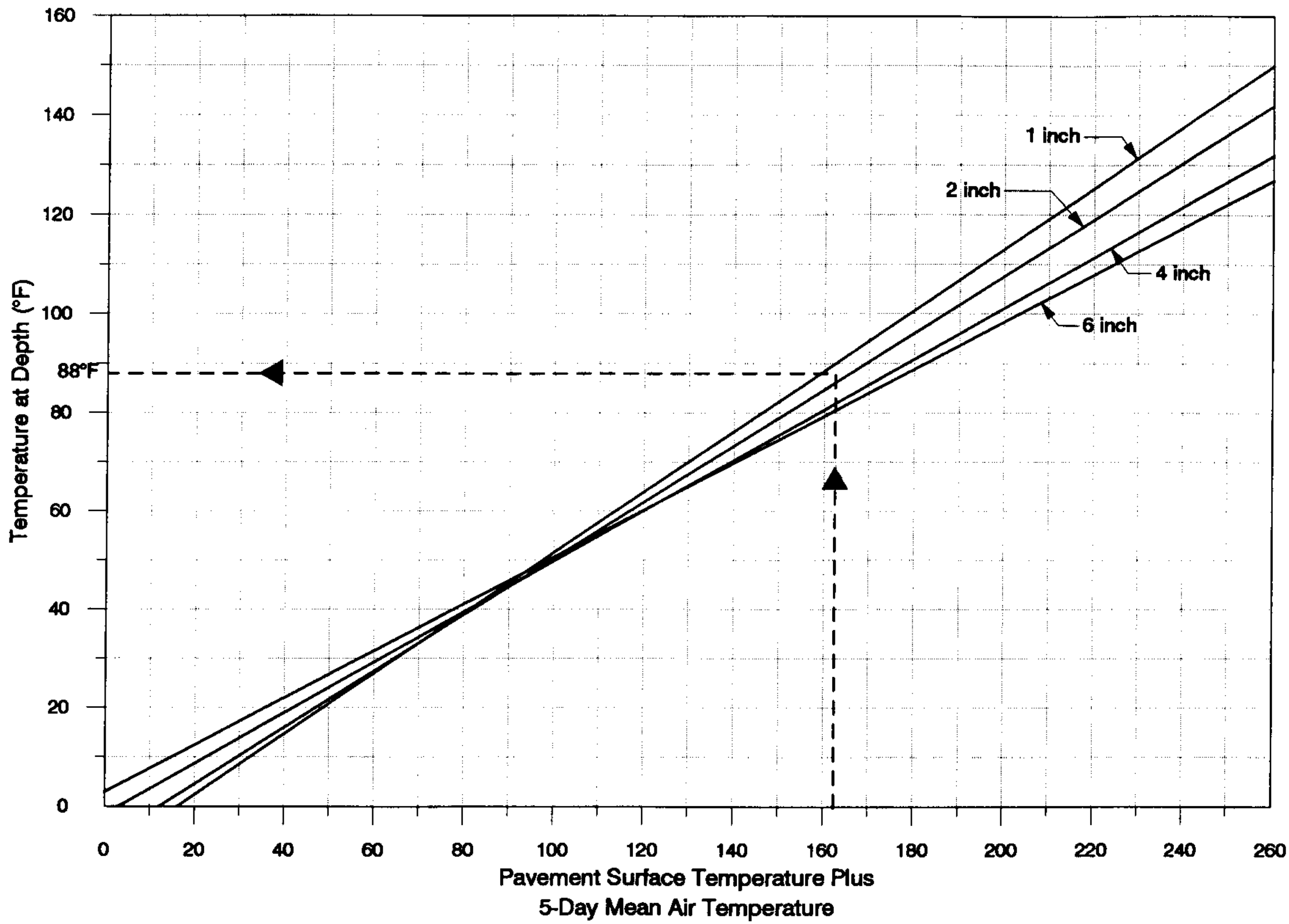
= **73.7°F**

Pavement surface temperature + Mean 5-day air temperature

89°F + 73.7°F = **162.7°F**

The average thickness of the concrete is 3.5/2 = **1.75 inches**

The figure shows that when you enter the graph with a thickness of 1.75 and a combined temperature of 166.7°F, the resulting average pavement temperature is <u>88°F</u>.



Temperature at Depth (°F)
160
140
120
100
88°F
80
60
40
20
0
0
20
40
60
80
100
120
140
160
180
200
220
240
260
1 inch
2 inch
4 inch
6 inch
Pavement Surface Temperature Plus
5-Day Mean Air Temperature

EXAMPLE OF ANALYSIS OF ROAD RATER PERFORMANCE TEST DATA

Step 1: Obtain performance test load and deflection data.

Applied Load (pounds)	D0 (mils)	Measured D1 (mils)	Deflections D2 (mils)	D3 (mils)	D4 (mils)
1211	1.48	1.15	0.90	0.62	0.36
1235	1.49	1.14	0.94	0.62	0.36
1204	1.44	1.12	0.88	0.62	0.32
1197	1.48	1.14	0.86	0.65	0.35
1189	1.43	1.14	0.87	0.62	0.35

Step 2: Obtain normalized deflections using the following equation:

Normalized Deflection = (Target Load / Applied Load) x Measured Deflection

Target Load (pounds)	D0 (mils)	Normalized D1 (mils)	Deflections D2 (mils)	D3 (mils)	D4 (mils)
1200	1.47	1.14	0.89	0.61	0.36
1200	1.45	1.11	0.91	0.60	0.35
1200	1.44	1.12	0.88	0.62	0.32
1200	1.48	1.14	0.86	0.65	0.35
1200	1.44	1.15	0.88	0.63	0.35
Average	1.46	1.13	0.88	0.62	0.35

Step 3: Obtain the percent difference between the normalized deflection and the average deflection as follows:

Percent Difference = (Normalized Deflection - Average Deflection) / Average Deflection

Target Load (pounds)	D0	Percent D1	Difference D2	D3	D4
1200	0.96%	0.71%	0.68%	1.93%	4.05%
1200	0.41%	1.94%	2.94%	3.54%	1.16%
1200	1.10%	1.06%	0.45%	0.32%	7.51%
1200	1.65%	0.71%	2.71%	4.50%	1.16%
1200	1.10%	1.59%	0.45%	1.29%	1.16%

If the percent difference is less than 5 percent for all deflections measured, the Road Rater is performing adequately. The average normalized deflections should be plotted on a graph of deflection versus date to observe any changes in deflections at each location from day to day or week to week.

EXAMPLE OF RELATIVE CALIBRATION PROCEDURE FOR THE DEFLECTION SENSORS

Test 1:

	Measured Deflections						Normalized Deflections				
Applied Load (pounds)	D1 Position A (mils)	D2 Position B (mils)	D3 Position C (mils)	D4 Position D (mils)	D5 Position E (mils)	Target Load (pounds)	D1 Position A (mils)	D2 Position B (mils)	D3 Position C (mils)	D4 Position D (mils)	D5 Position E (mils)
1211	1.52	1.54	1.56	1.55	1.55	1200	1.51	1.53	1.55	1.54	1.54
1235	1.51	1.58	1.61	1.60	1.52	1200	1.47	1.54	1.56	1.55	1.48
1204	1.51	1.51	1.57	1.57	1.51	1200	1.50	1.50	1.56	1.56	1.50
1197	1.51	1.49	1.52	1.51	1.55	1200	1.51	1.49	1.52	1.51	1.55
1189	1.49	1.52	1.54	1.56	1.54	1200	1.50	1.53	1.55	1.57	1.55

Test 2:

	Measured Deflections						Normalized Deflections				
Applied Load (pounds)	D1 Position B (mils)	D2 Position C (mils)	D3 Position D (mils)	D4 Position E (mils)	D5 Position A (mils)	Target Load (pounds)	D1 Position B (mils)	D2 Position C (mils)	D3 Position D (mils)	D4 Position E (mils)	D5 Position A (mils)
1234	1.53	1.55	1.52	1.54	1.55	1200	1.49	1.51	1.48	1.50	1.51
1201	1.48	1.50	1.46	1.55	1.54	1200	1.48	1.50	1.46	1.55	1.54
1187	1.49	1.53	1.53	1.53	1.53	1200	1.51	1.55	1.55	1.55	1.55
1190	1.51	1.53	1.52	1.52	1.54	1200	1.52	1.54	1.53	1.53	1.55
1243	1.52	1.61	1.54	1.57	1.55	1200	1.47	1.55	1.49	1.52	1.50

Test 3:

	Measured Deflections						Normalized Deflections				
Applied Load (pounds)	D1 Position C (mils)	D2 Position D (mils)	D3 Position E (mils)	D4 Position A (mils)	D5 Position B (mils)	Target Load (pounds)	D1 Position C (mils)	D2 Position D (mils)	D3 Position E (mils)	D4 Position A (mils)	D5 Position B (mils)
1204	1.53	1.55	1.52	1.54	1.57	1200	1.52	1.54	1.51	1.53	1.56
1212	1.52	1.53	1.56	1.57	1.54	1200	1.50	1.51	1.54	1.55	1.52
1235	1.52	1.57	1.58	1.58	1.58	1200	1.48	1.53	1.54	1.54	1.54
1186	1.46	1.53	1.54	1.53	1.53	1200	1.48	1.55	1.56	1.55	1.55
1199	1.51	1.50	1.53	1.52	1.55	1200	1.51	1.50	1.53	1.52	1.55

EXAMPLE OF RELATIVE CALIBRATION PROCEDURE FOR THE DEFLECTION SENSORS (Continued)

Test 4:

	Measured	Deflections					Normalized	Deflections			
Applied Load (pounds)	D1 Position D (mils)	D2 Position E (mils)	D3 Position A (mils)	D4 Position B (mils)	D5 Position C (mils)	Target Load (pounds)	D1 Position D (mils)	D2 Position E (mils)	D3 Position A (mils)	D4 Position B (mils)	D5 Position C (mils)
1209	1.52	1.53	1.55	1.52	1.54	1200	1.51	1.52	1.54	1.51	1.53
1255	1.55	1.60	1.62	1.63	1.62	1200	1.48	1.53	1.55	1.56	1.55
1242	1.52	1.60	1.60	1.60	1.62	1200	1.47	1.55	1.55	1.55	1.57
1204	1.51	1.57	1.54	1.58	1.56	1200	1.50	1.56	1.53	1.57	1.55
1219	1.49	1.56	1.54	1.56	1.54	1200	1.47	1.54	1.52	1.54	1.52

Test 5:

	Measured	Deflections					Normalized	Deflections			
Applied Load (pounds)	D1 Position E (mils)	D2 Position A (mils)	D3 Position B (mils)	D4 Position C (mils)	D5 Position D (mils)	Target Load (pounds)	D1 Position E (mils)	D2 Position A (mils)	D3 Position B (mils)	D4 Position C (mils)	D5 Position D (mils)
1205	1.51	1.52	1.57	1.56	1.57	1200	1.50	1.51	1.56	1.55	1.56
1254	1.54	1.59	1.57	1.63	1.60	1200	1.47	1.52	1.50	1.56	1.53
1233	1.53	1.55	1.56	1.59	1.61	1200	1.49	1.51	1.52	1.55	1.57
1212	1.50	1.55	1.57	1.56	1.58	1200	1.49	1.53	1.55	1.54	1.56
1232	1.54	1.59	1.58	1.56	1.58	1200	1.50	1.55	1.54	1.52	1.54
					Average		1.49	1.53	1.53	1.54	1.54

The average is the average value of the 25 deflection readings for each sensor normalized to 1200 pounds.

Overall average 1.53

The overall average is the average value of all normalized deflection readings for all sensors, a total of 125 deflection readings:

	D1	D2	D3	D4	D5
Ratio	1.0222	0.9992	0.9966	0.9907	0.9919

The ratio is the ratio of the overall average to the average for each sensor. Since the ratio for each sensor is between 0.95 and 1.05 the sensors are functioning properly. The calculated ratios are the new calibration factors and can be entered into the ROAD.CFG file on your Road Rater software by running the SENSMULT program.