Mn/DOT Flexible Pavement Design

Mechanistic-Empirical Method

Pavement Design Systems and Pavement Performance Models

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Acknowledgements

- Icelandic Road Administration
- Haraldur Sigursteinsson
- Nordic Road Association
- NordFoU Project

Pavement Design at Mn/DOT

- Current procedure
  - Subgrade soil R-value, traffic, rule-of-thumb materials properties
  - Relates to ride
- MnPAVE procedure
  - Modulus of all layers, base strength, repeated load damage in HMA and subgrade
  - Relates to structural distresses – cracking, rutting

Background

WESLEA

- Layered Elastic Analysis (5 Layers)
- Developed at U.S. Army Engineer Waterways Experiment Station (Van Cauwelaert *et al*, 1986)

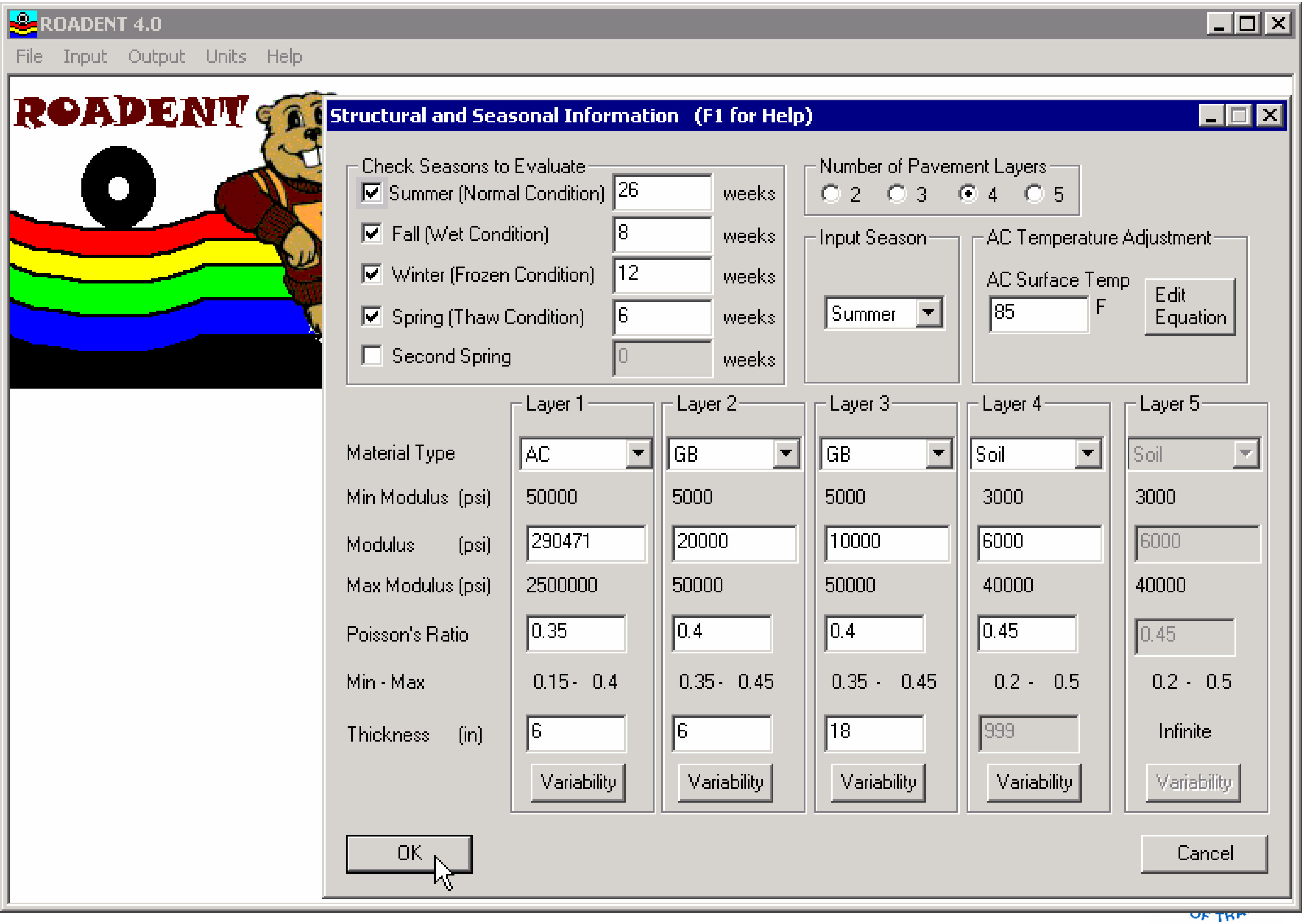
ROADENT

University of Minnesota (1996-1999)

Dr. David Timm – Auburn University

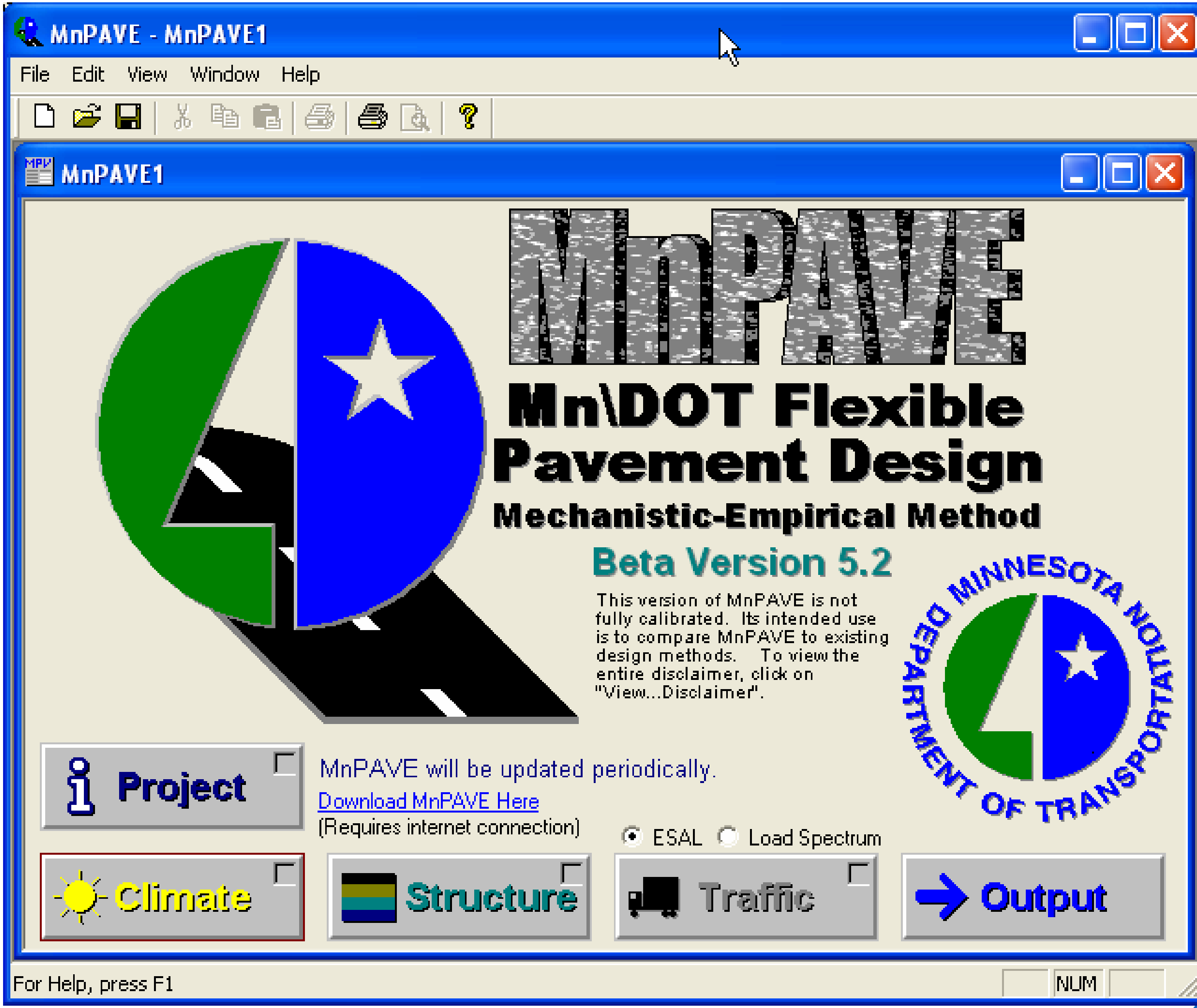
Dr. David Newcomb – NAPA

Dr. Bjorn Birgisson – University of Florida

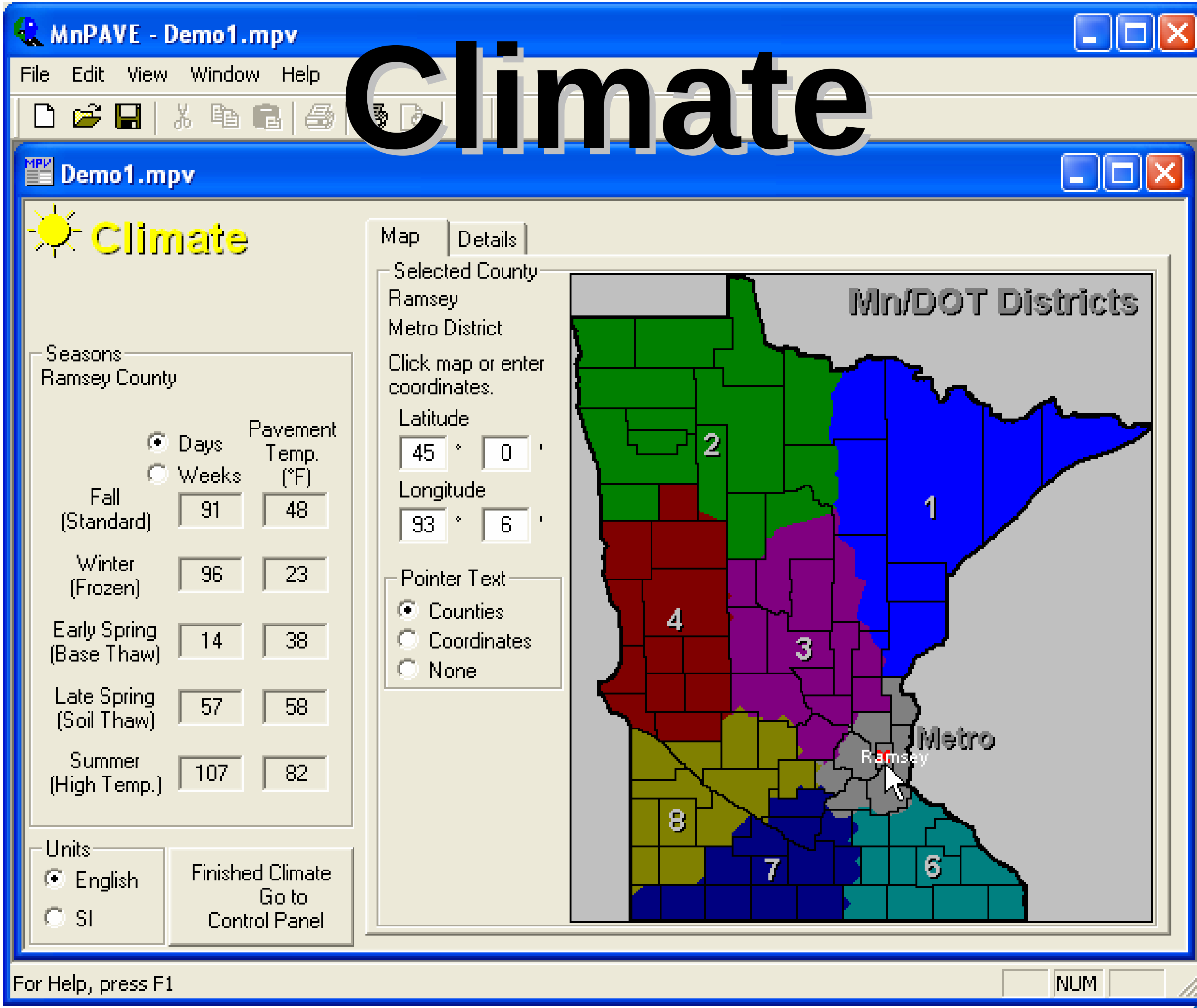

ROADENT 4.0
File
Input
Output
Units
Help
ROADENT
Structural and Seasonal Information (F1 for Help)
Check Seasons to Evaluate
Summer (Normal Condition) 26 weeks
Fall (Wet Condition) 8 weeks
Winter (Frozen Condition) 12 weeks
Spring (Thaw Condition) 6 weeks
Second Spring 0 weeks
Number of Pavement Layers
2 3 4 5
Input Season
Summer
AC Temperature Adjustment
AC Surface Temp
85 F
Edit Equation
Layer 1
Layer 2
Layer 3
Layer 4
Layer 5
Material Type AC GB GB Soil Soil
Min Modulus (psi) 50000 5000 5000 3000 3000
Modulus (psi) 290471 20000 10000 6000 6000
Max Modulus (psi) 2500000 50000 50000 40000 40000
Poisson's Ratio 0.35 0.4 0.4 0.45 0.45
Min - Max 0.15 - 0.4 0.35 - 0.45 0.35 - 0.45 0.2 - 0.5 0.2 - 0.5
Thickness (in) 6 6 18 999 Infinite
Variability
Variability
Variability
Variability
Variability
OK
Cancel

MnPAVE Pavement Design

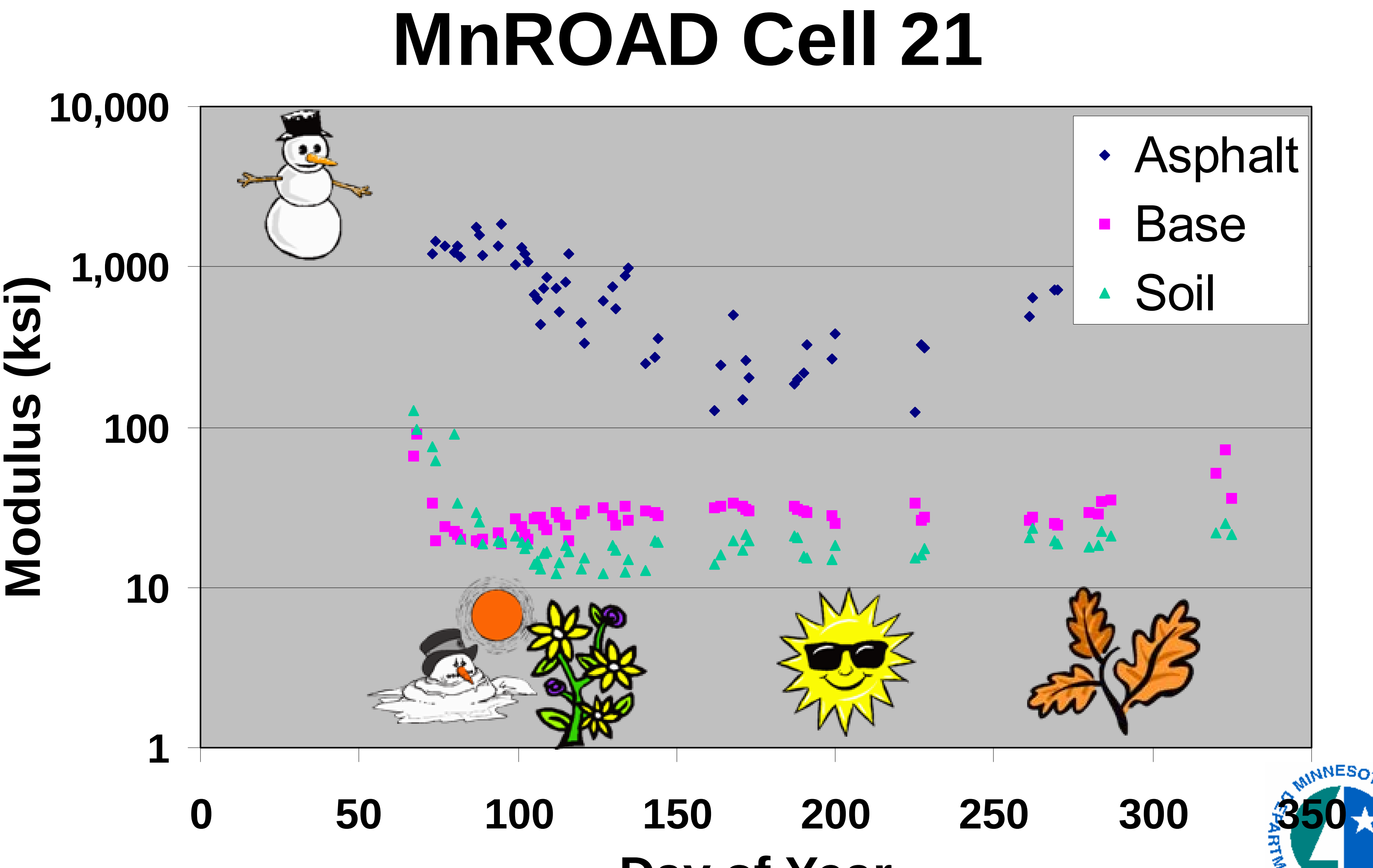
- Climate model
- More material types and default properties
- Lab and field test results
- Updated performance models


MnPAVE - MnPAVE1
File Edit View Window Help
MnPAVE1
MnPAVE
Mn\DOT Flexible
Pavement Design
Mechanistic-Empirical Method
Beta Version 5.2
This version of MnPAVE is not fully calibrated. Its intended use is to compare MnPAVE to existing design methods. To view the entire disclaimer, click on "View...Disclaimer".
MINNESOTA DEPARTMENT OF TRANSPORTATION
Project
MnPAVE will be updated periodically.
Download MnPAVE Here
(Requires internet connection)
ESAL
Load Spectrum
Climate
Structure
Traffic
Output
For Help, press F1
NUM

Climate


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
Climate
Seasons
Ramsey County
Days
Weeks
Pavement Temp. (°F)
Fall (Standard) 91 48
Winter (Frozen) 96 23
Early Spring (Base Thaw) 14 38
Late Spring (Soil Thaw) 57 58
Summer (High Temp.) 107 82
Units
English
SI
Finished Climate Go to Control Panel
Map
Details
Selected County
Ramsey
Metro District
Click map or enter coordinates.
Latitude
45 ° 0 '
Longitude
93 ° 6 '
Pointer Text
Counties
Coordinates
None
Mn/DOT Districts
1
2
3
4
6
7
8
Metro
Ramsey
For Help, press F1
NUM

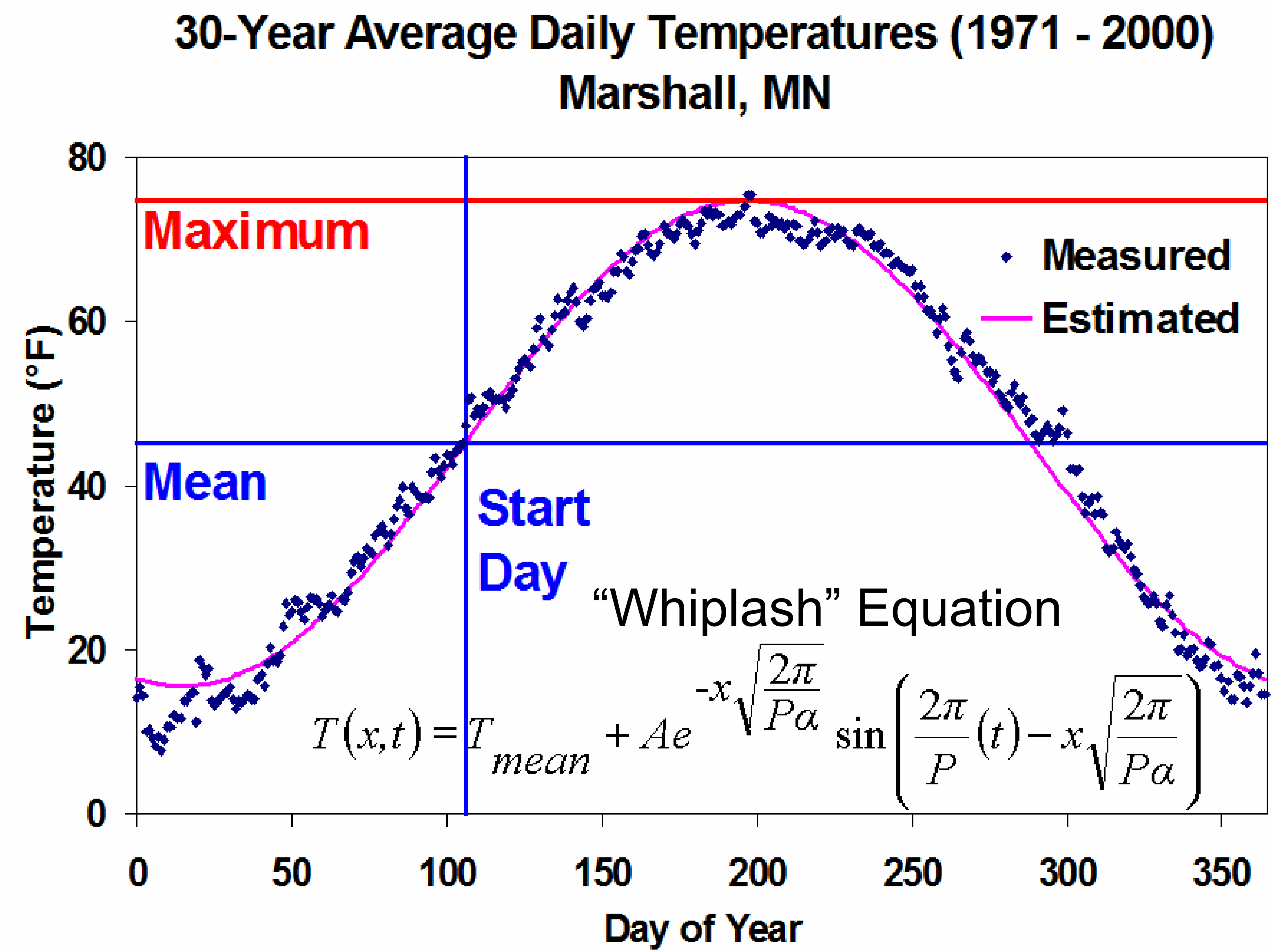
Seasons

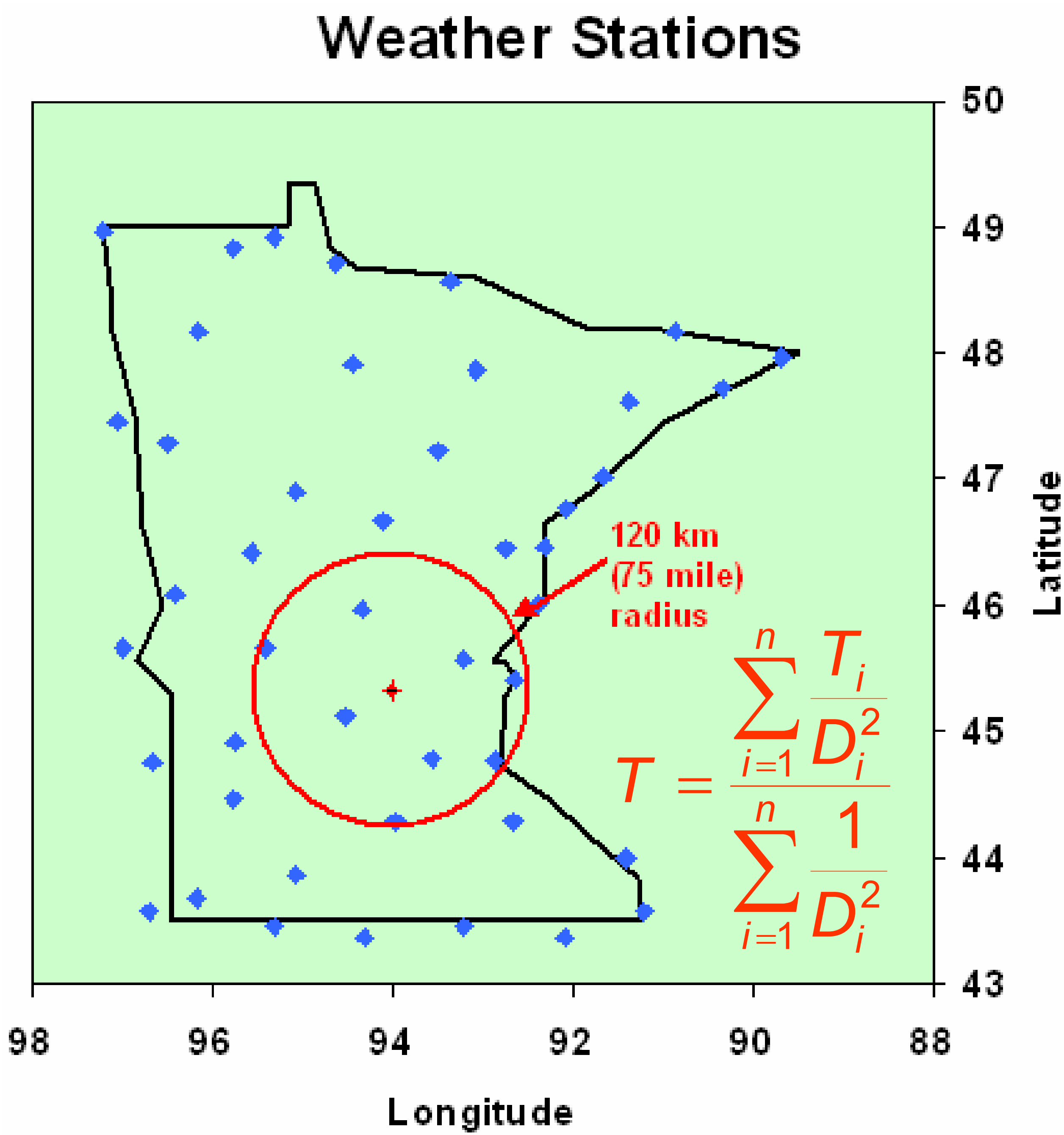

MnROAD Cell 21
10,000
1,000
100
10
1
Modulus (ksi)
0
50
100
150
200
250
300
350
Day of Year
Asphalt
Base
Soil

Criteria for Determining the Beginning of MnPAVE Seasons

Season	Criteria
Fall	3-day Average Temperature < 17 °C
Winter	Freezing Index > 90 °C-days
Spring Thaw	Thawing Index > 15 °C-days
Spring Recovery	2 Weeks After Start of Spring Thaw
Summer	3-day Average Temperature > 17 °C

Temperature Model



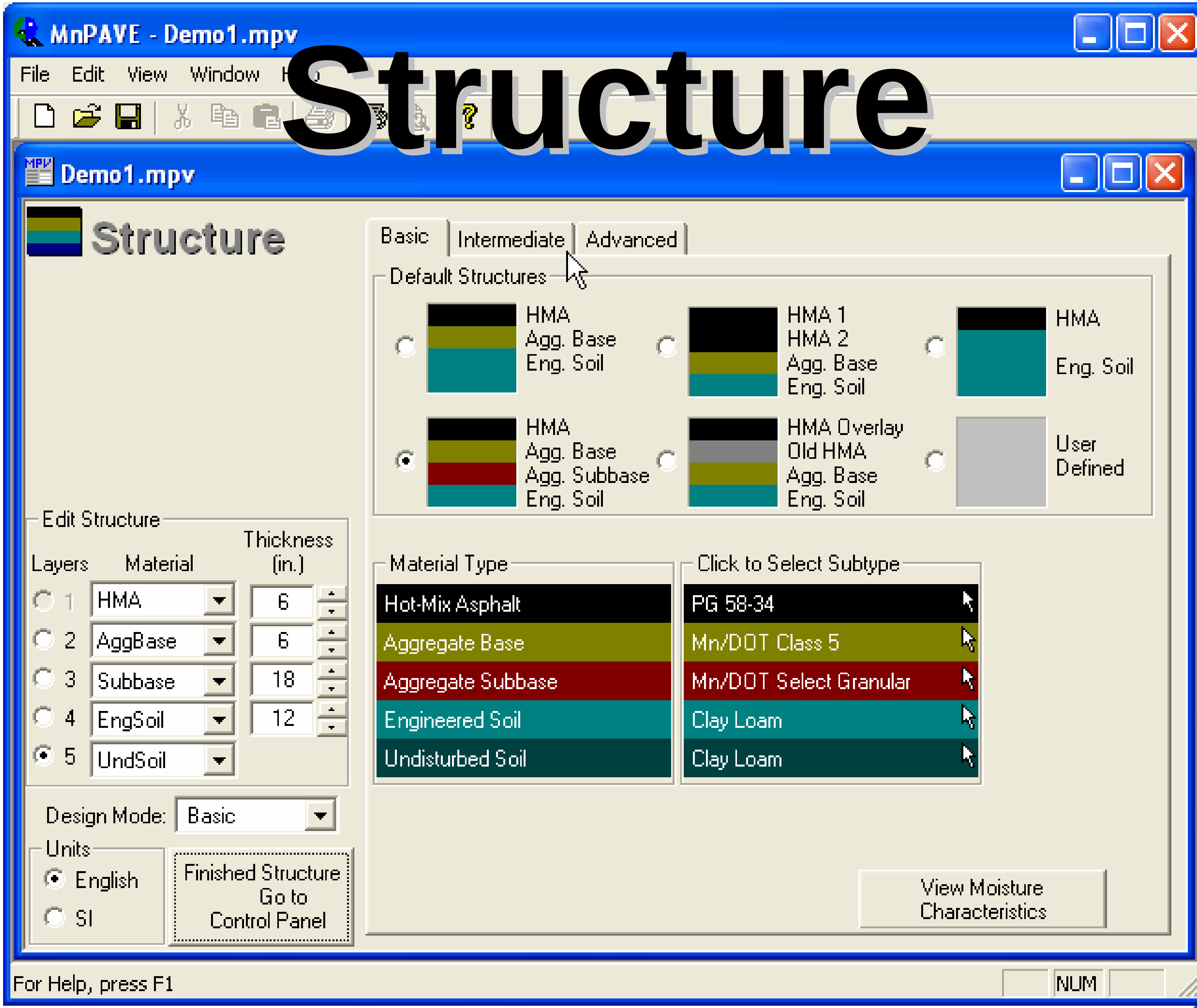


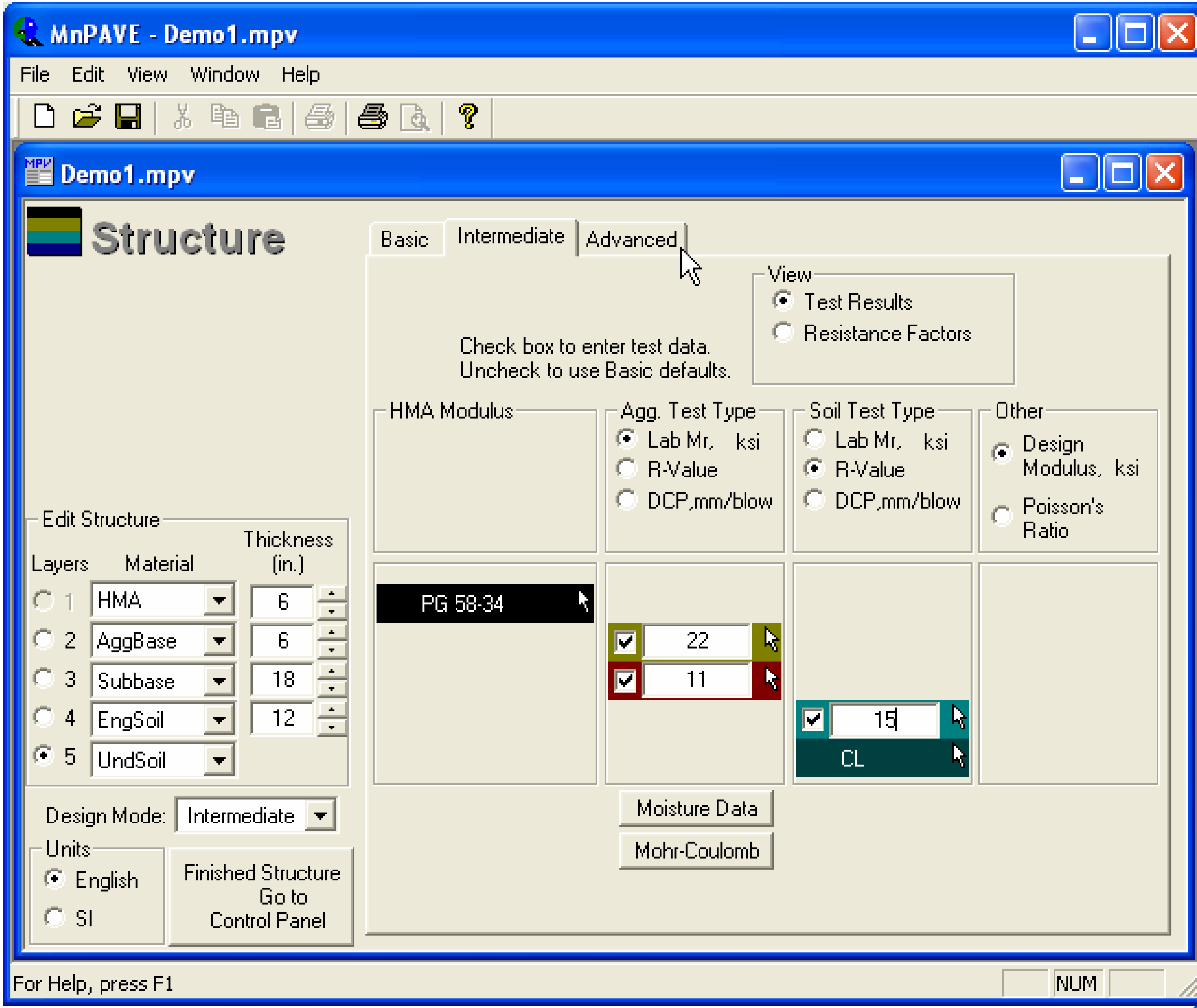
$$T = \frac{\sum_{i=1}^{n} \frac{T_i}{D_i^2}}{\sum_{i=1}^{n} \frac{1}{D_i^2}}$$

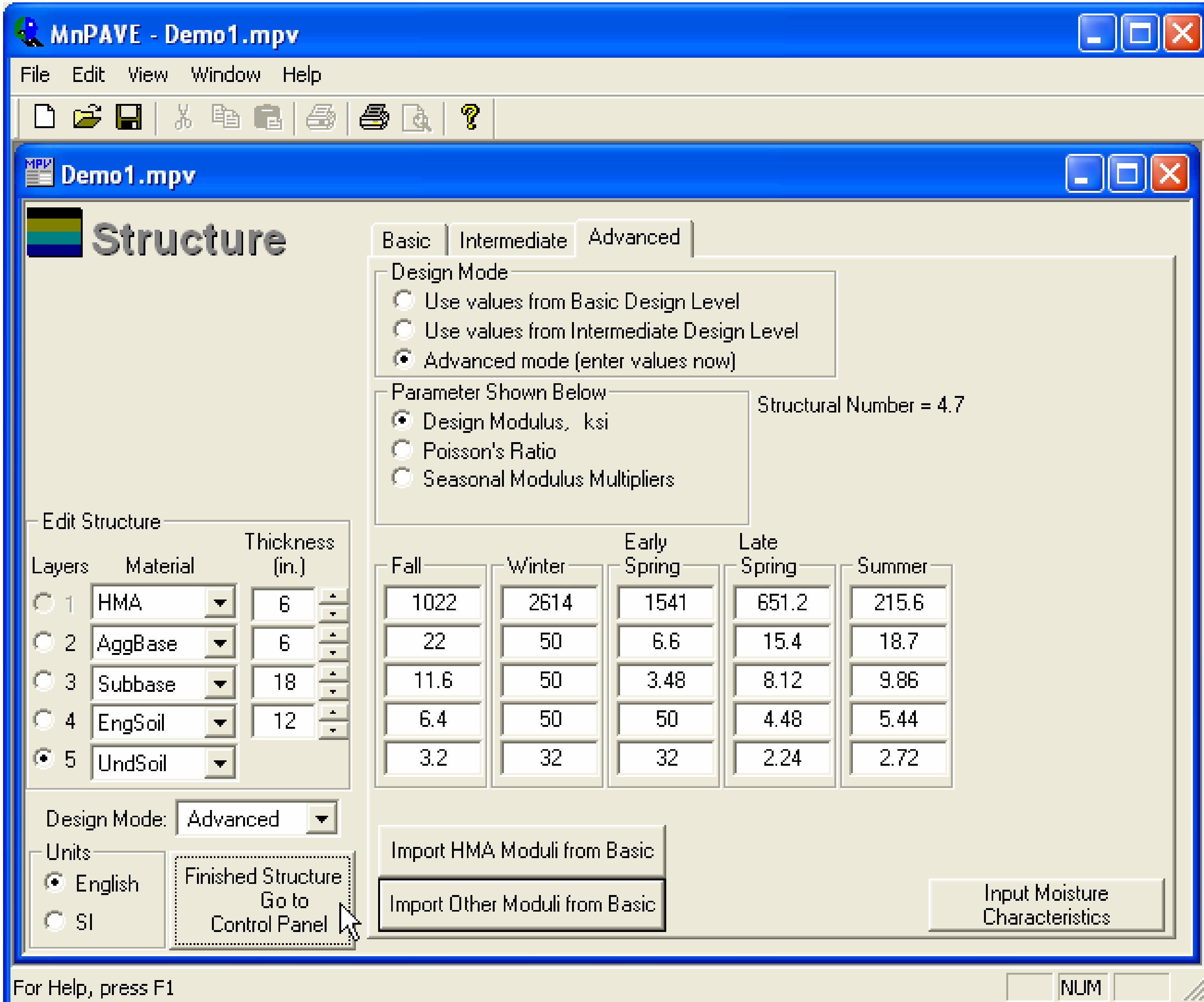
5 Seasons vs. 52 Weeks

- Number of times the asphalt modulus (stiffness) is calculated.
- Affects the calculation time.
- Wide range of pavements were simulated.
- Design thickness differed by no more than 0.1 in.
- Default MnPAVE procedure has 5 seasons.

Structure


MnPAVE - Demo1.mpv
File Edit View Window
Demo1.mpv
Structure
Basic
Intermediate
Advanced
Default Structures
HMA
Agg. Base
Eng. Soil
HMA 1
HMA 2
Agg. Base
Eng. Soil
HMA
Eng. Soil
HMA
Agg. Base
Agg. Subbase
Eng. Soil
HMA Overlay
Old HMA
Agg. Base
Eng. Soil
User Defined
Edit Structure
Layers
Material
Thickness (in.)
1 HMA 6
2 AggBase 6
3 Subbase 18
4 EngSoil 12
5 UndSoil
Material Type
Hot-Mix Asphalt
Aggregate Base
Aggregate Subbase
Engineered Soil
Undisturbed Soil
Click to Select Subtype
PG 58-34
Mn/DOT Class 5
Mn/DOT Select Granular
Clay Loam
Clay Loam
Design Mode: Basic
Units
English
SI
Finished Structure Go to Control Panel
View Moisture Characteristics
For Help, press F1
NUM


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
Structure
Basic
Intermediate
Advanced
View
Test Results
Resistance Factors
Check box to enter test data.
Uncheck to use Basic defaults.
HMA Modulus
Agg. Test Type
Lab Mr, ksi
R-Value
DCP,mm/blow
Soil Test Type
Lab Mr, ksi
R-Value
DCP,mm/blow
Other
Design Modulus, ksi
Poisson's Ratio
PG 58-34
22
11
15
CL
Moisture Data
Mohr-Coulomb
Edit Structure
Layers
Material
Thickness (in.)
1 HMA 6
2 AggBase 6
3 Subbase 18
4 EngSoil 12
5 UndSoil
Design Mode: Intermediate
Units
English
SI
Finished Structure Go to Control Panel
For Help, press F1
NUM


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
Structure
Basic
Intermediate
Advanced
Design Mode
Use values from Basic Design Level
Use values from Intermediate Design Level
Advanced mode (enter values now)
Parameter Shown Below
Design Modulus, ksi
Poisson's Ratio
Seasonal Modulus Multipliers
Structural Number = 4.7
Edit Structure
Layers
Material
Thickness (in.)
1 HMA 6
2 AggBase 6
3 Subbase 18
4 EngSoil 12
5 UndSoil
Fall
Winter
Early Spring
Late Spring
Summer
1022 2614 1541 651.2 215.6
22 50 6.6 15.4 18.7
11.6 50 3.48 8.12 9.86
6.4 50 50 4.48 5.44
3.2 32 32 2.24 2.72
Design Mode: Advanced
Units
English
SI
Finished Structure Go to Control Panel
Import HMA Moduli from Basic
Import Other Moduli from Basic
Input Moisture Characteristics
For Help, press F1
NUM

Material Properties

- New Asphalt
- Existing Asphalt (overlay design)
- Aggregate Base/Subbase
- Soils

Witczak Equation

$$\log E = a_0 + a_1 p_{200} + a_2 (p_{200})^2 + a_3 p_4 + a_4 V_a + a_5 \frac{V_{beff}}{V_{beff} + V_a}$$

$$+ \frac{a_6 + a_7 p_4 + a_8 p_{3/8} + a_9 (p_{3/8})^2 + a_{10} p_{3/4}}{1 + e^{(a_{11} + a_{12} \log f + a_{13} 2 \log \eta)}}$$

Where:

E = 10^{-5} x Dynamic Modulus (psi)

η = 10^{-8} x Dynamic Viscosity (cP)

P_b = binder content (% by wt. of mix)

V_a = Air voids (% by volume)

P_{ba} = Absorption (% by wt. of aggregate)

G_b = specific gravity of binder

G_{sb} = Bulk specific gravity of aggregate

f = Load frequency (Hz)

V_{beff} = Effective binder content (% by vol.)

$p_{3/4}$ = Cumulative % retained on 3/4" sieve

$p_{3/8}$ = Cumulative % retained on 3/8" sieve

p_4 = Cumulative % retained on No. 4 sieve

p_{200} = Percent passing No. 200 sieve

Thompson (ILLI-PAVE) Equation

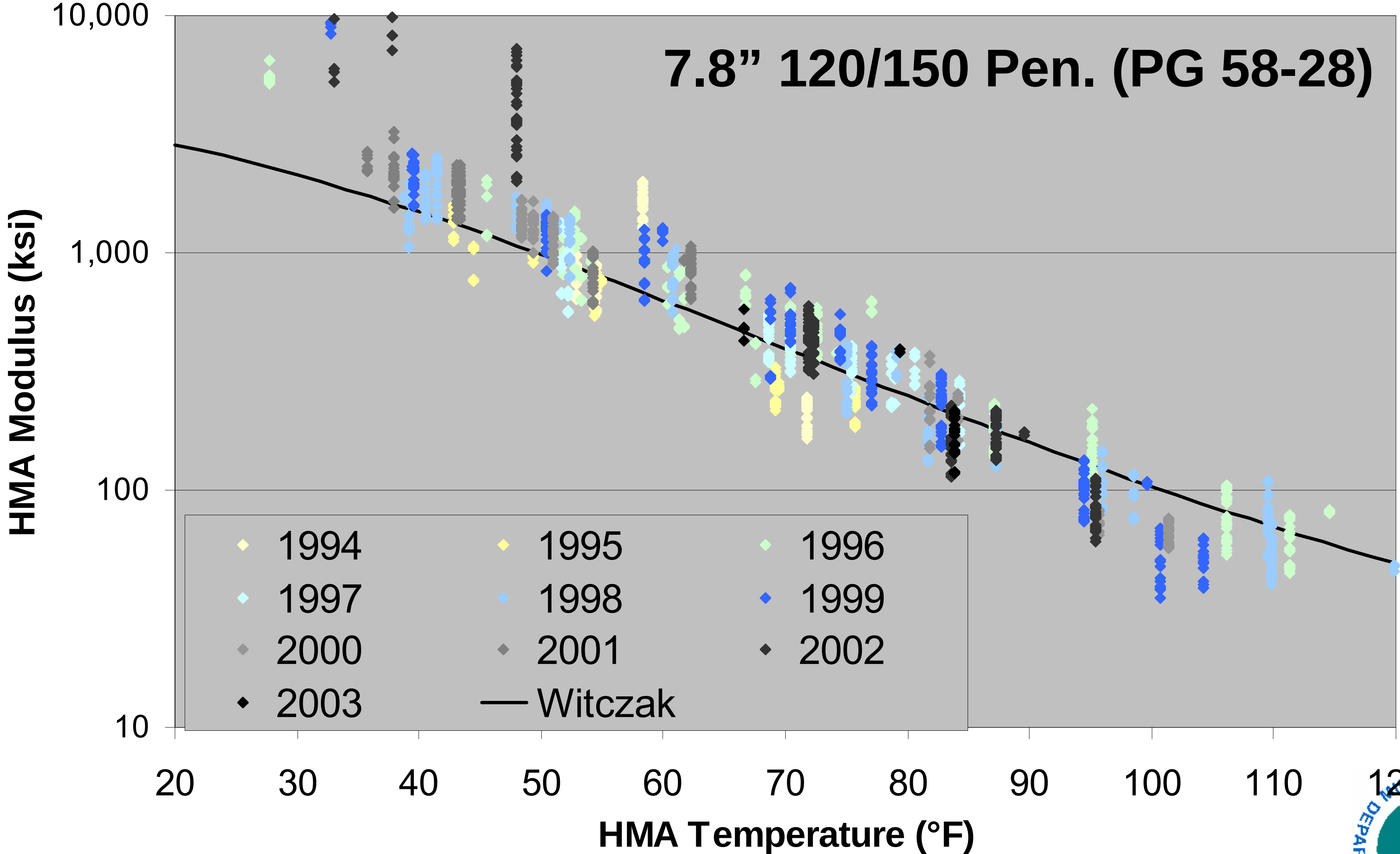
$$\log_{10} E_{AC} = 1.48 - 1.76 \log_{10}\left(\frac{AREA}{D_0}\right) + 0.26\left(\frac{AREA}{T_{AC}}\right)$$

Where:

$$AREA = 6\left(1 + \frac{2D_1}{D_0} + \frac{2D_2}{D_0} + \frac{D_3}{D_0}\right)$$

E_{AC} = Modulus of the HMA layer (ksi)
T_{AC} = Temperature of the HMA layer (°F)
D_0 = Deflection at center of load (mils)
D_1 = Deflection at 12 in. (305 mm) from center of load
D_2 = Deflection at 24 in. (610 mm) from center of load
D_3 = Deflection at 36 in. (914 mm) from center of load

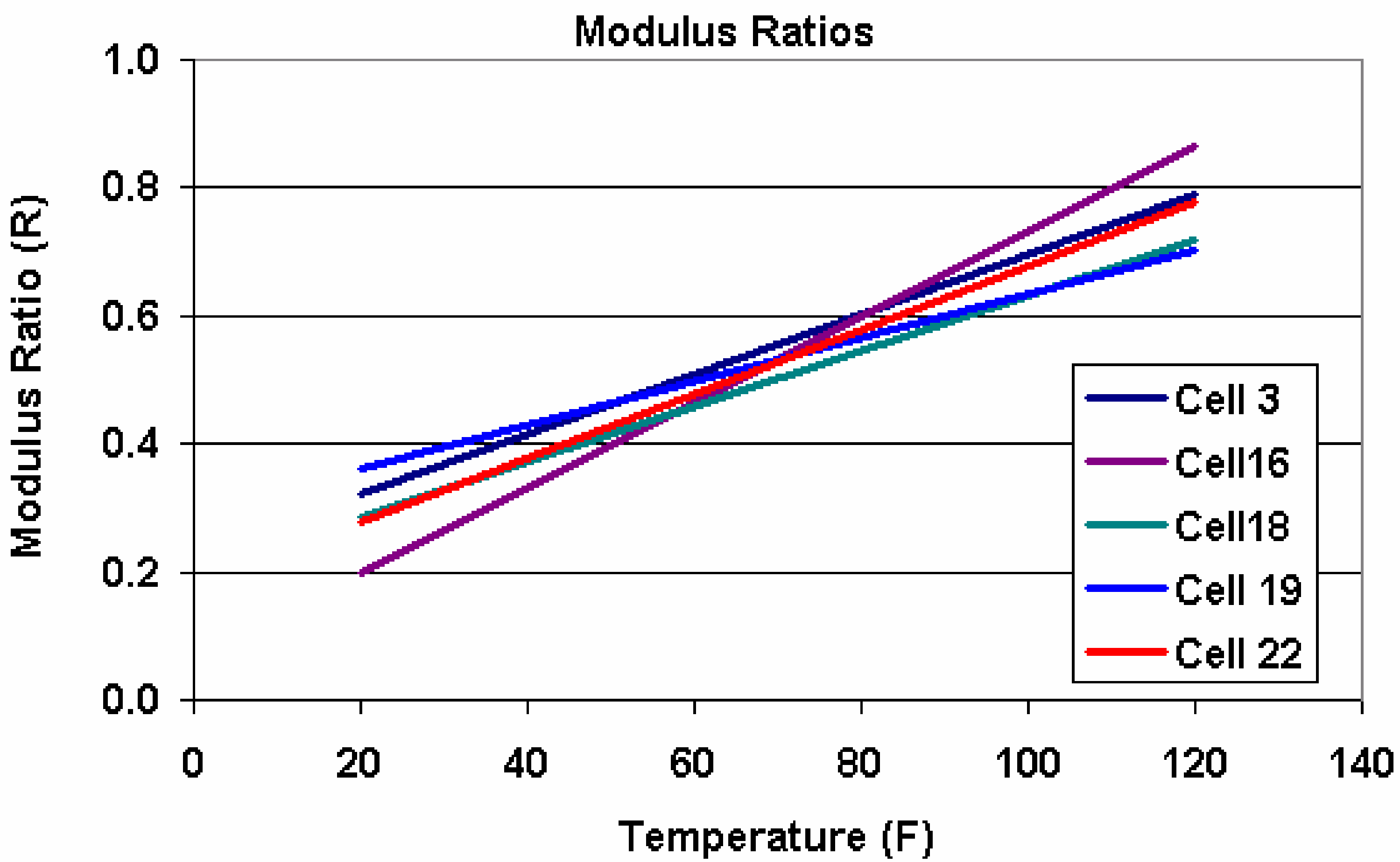
Cell 20 Modulus Comparison 1994-2003
Witczak and Thompson Equations

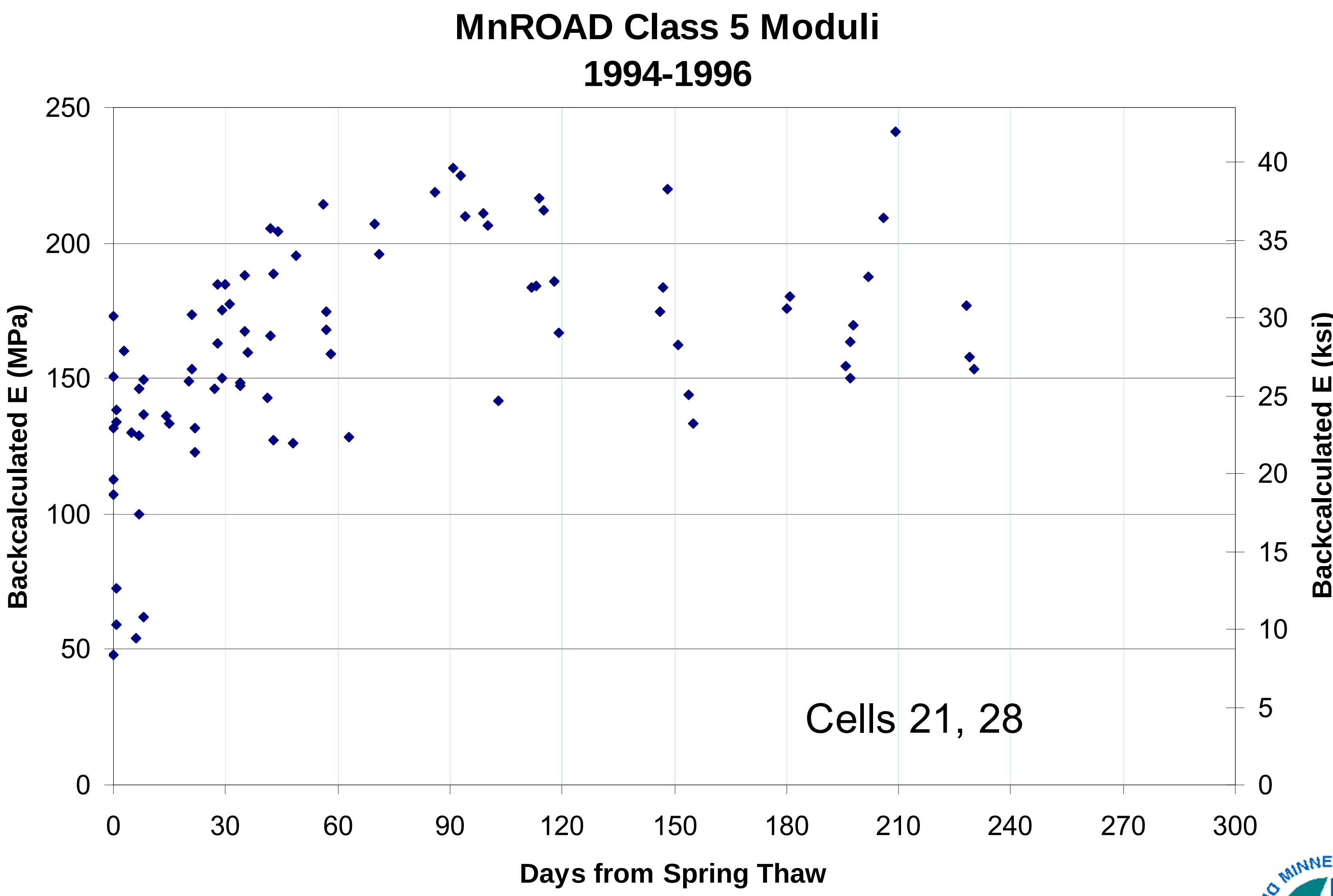


Modulus Reduction Factor

– Modulus Ratio (R)

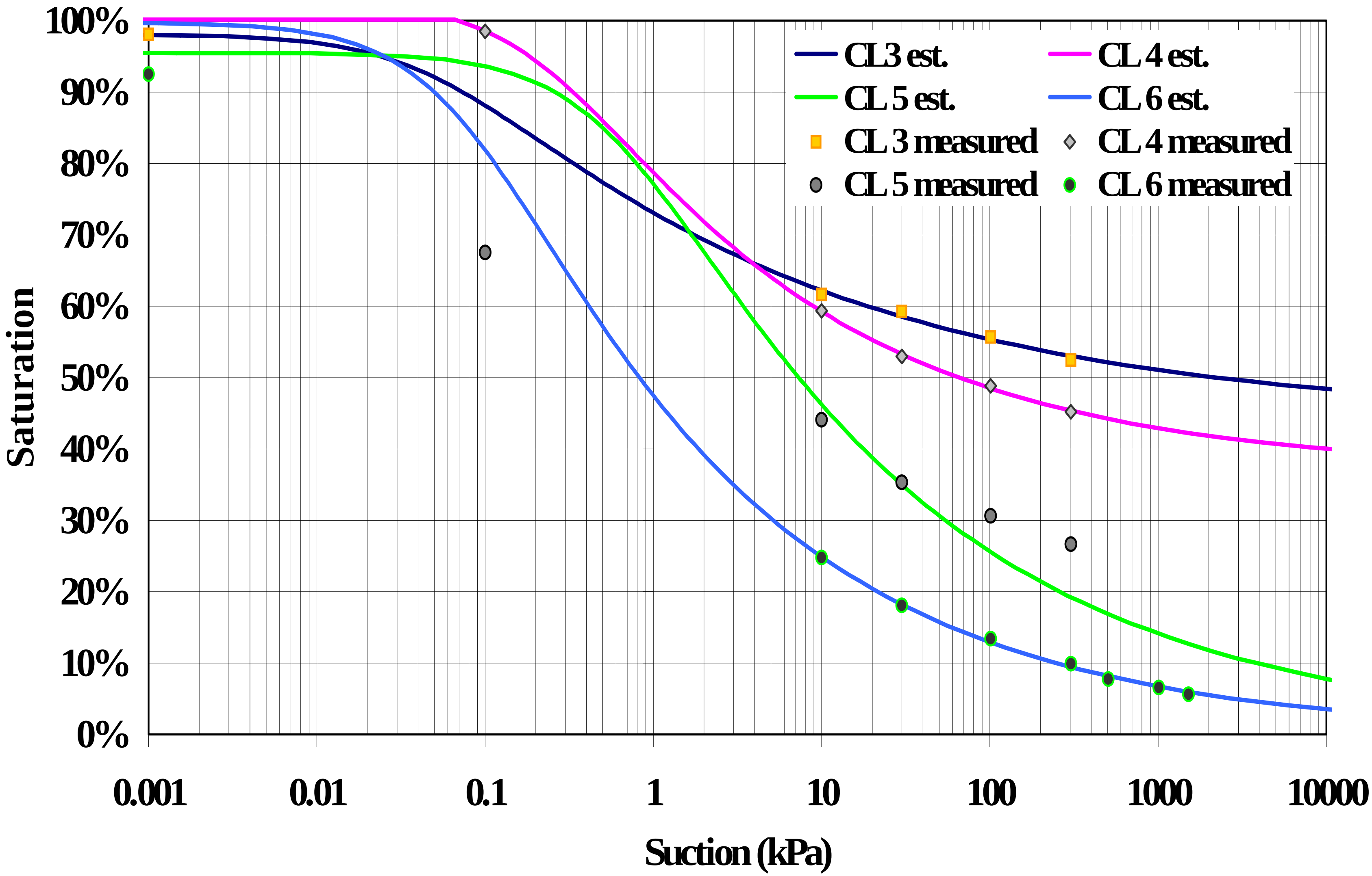
- **R= E*(near crack)/E* (between cracks)**



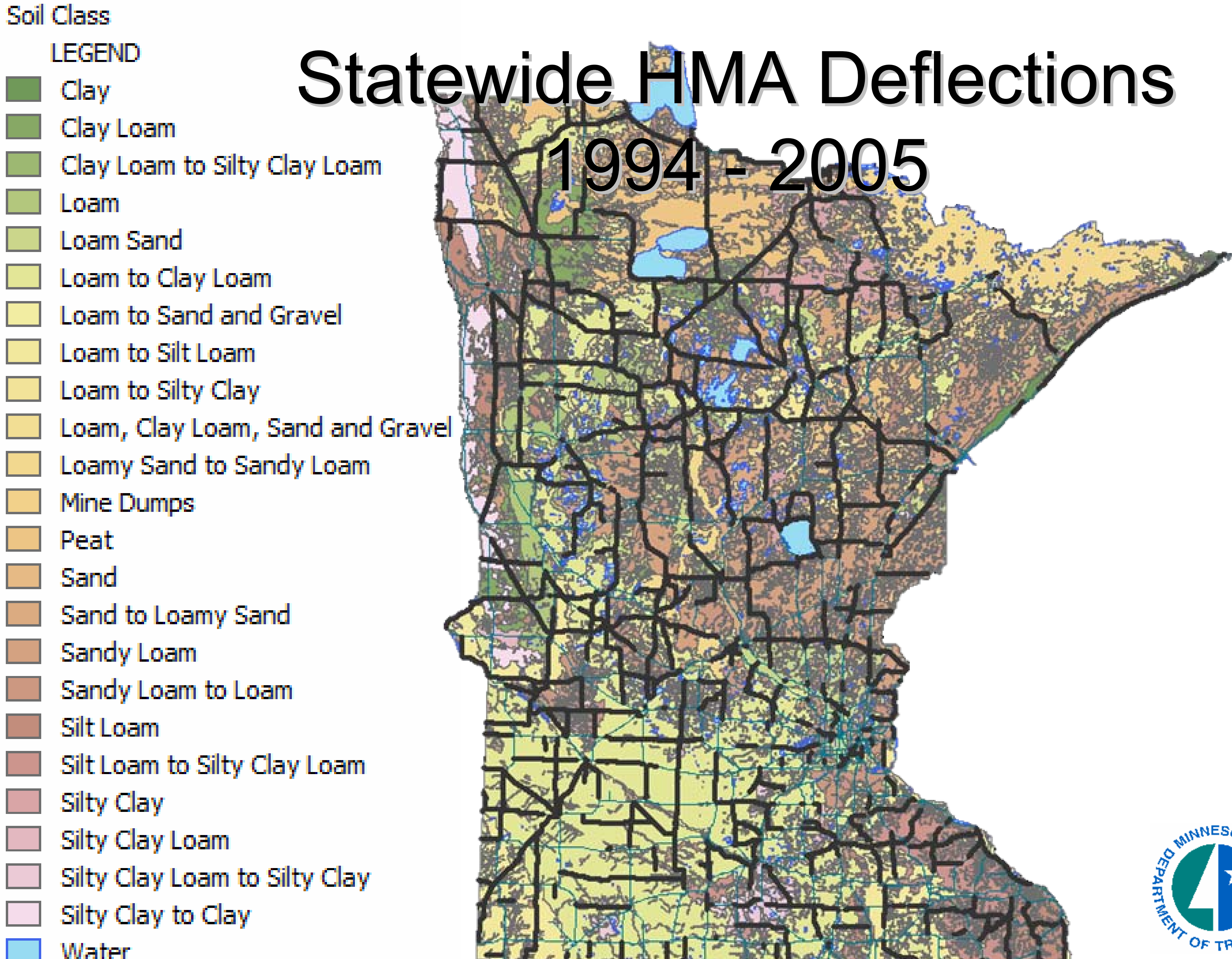


MnROAD Class 5 Moduli
1994-1996
Backcalculated E (MPa)
Backcalculated E (ksi)
Days from Spring Thaw
Cells 21, 28
0
50
100
150
200
250
0
5
10
15
20
25
30
35
40
0
30
60
90
120
150
180
210
240
270
300

Unsaturated Properties



Statewide HMA Deflections
1994 - 2005



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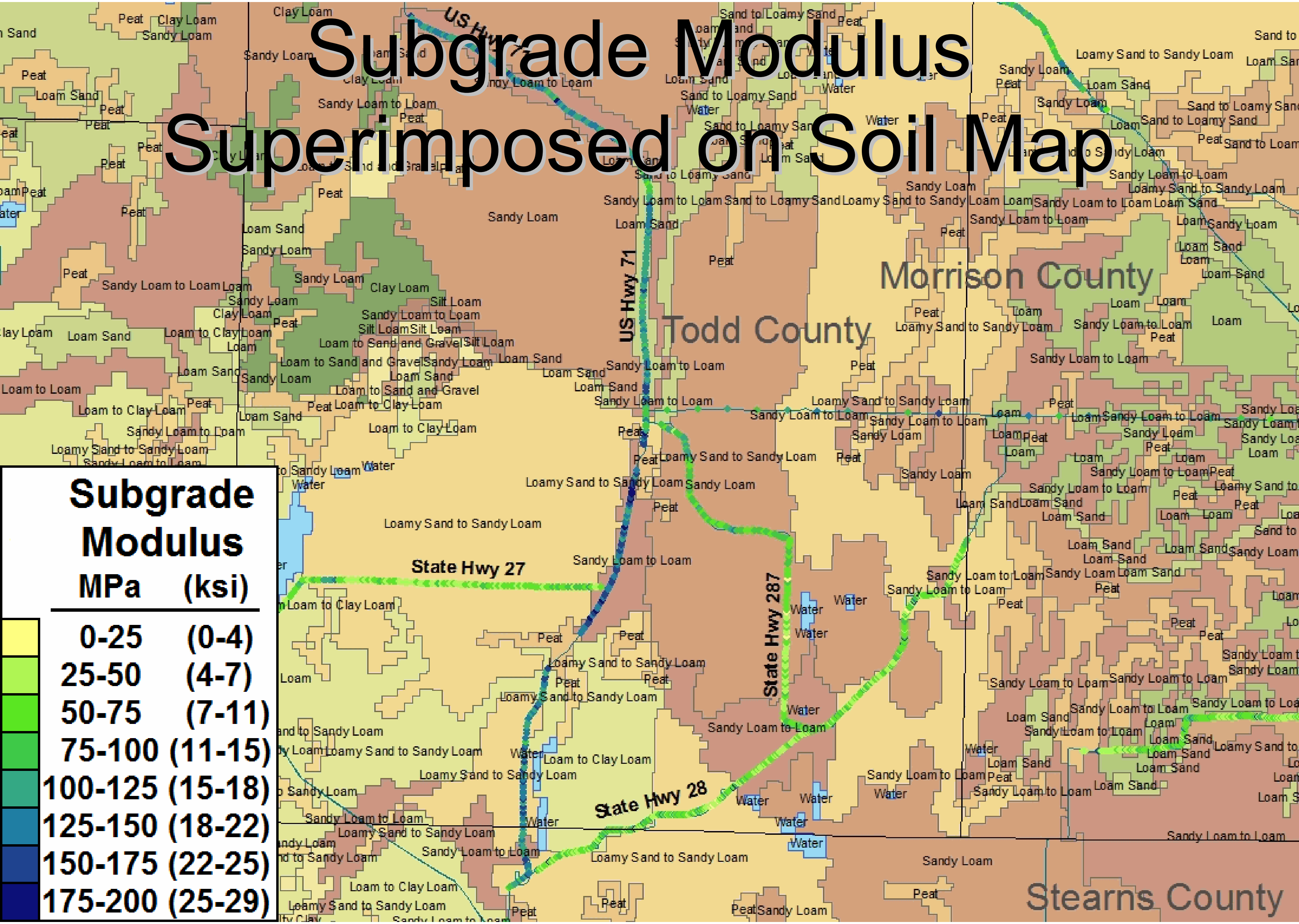
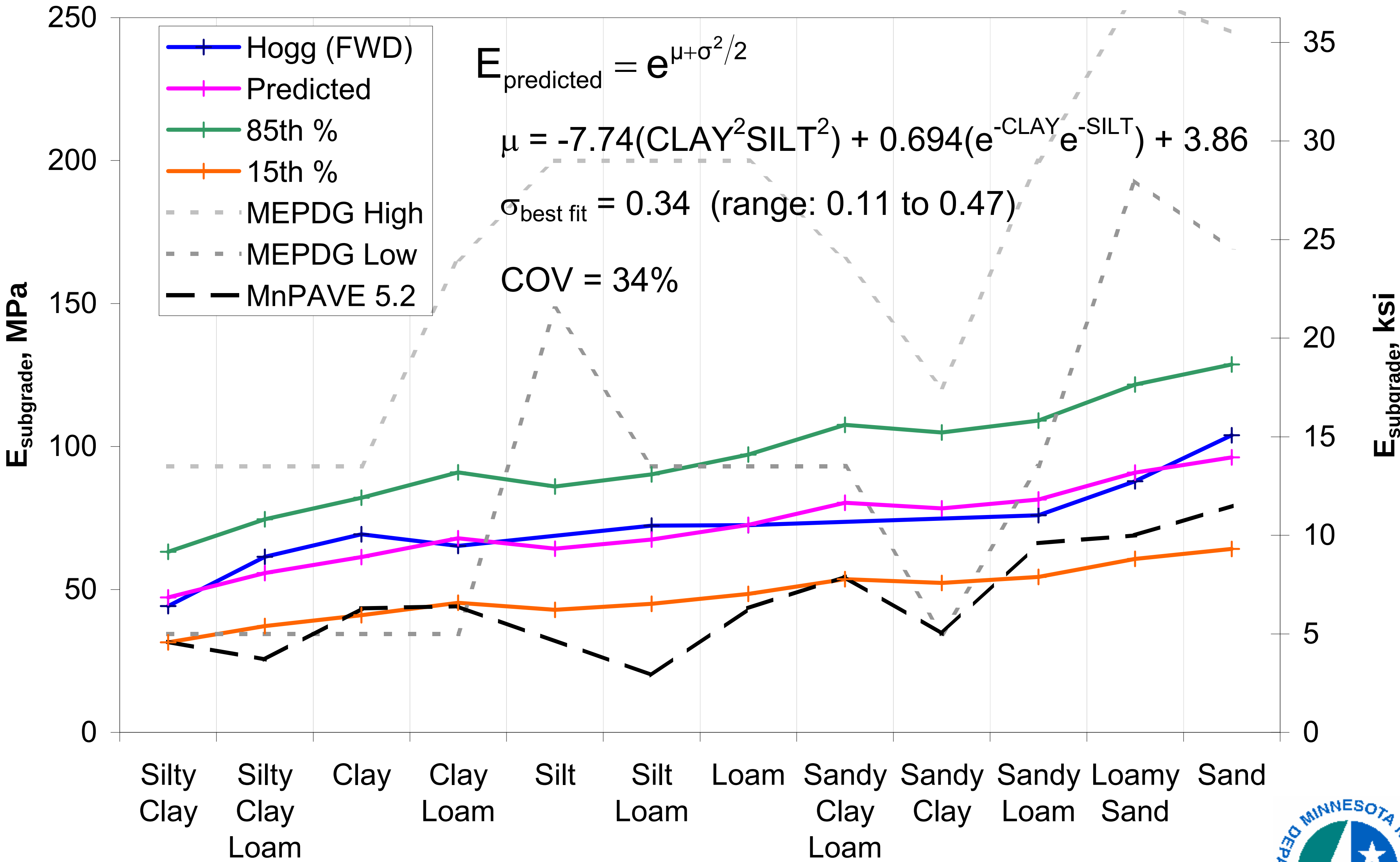
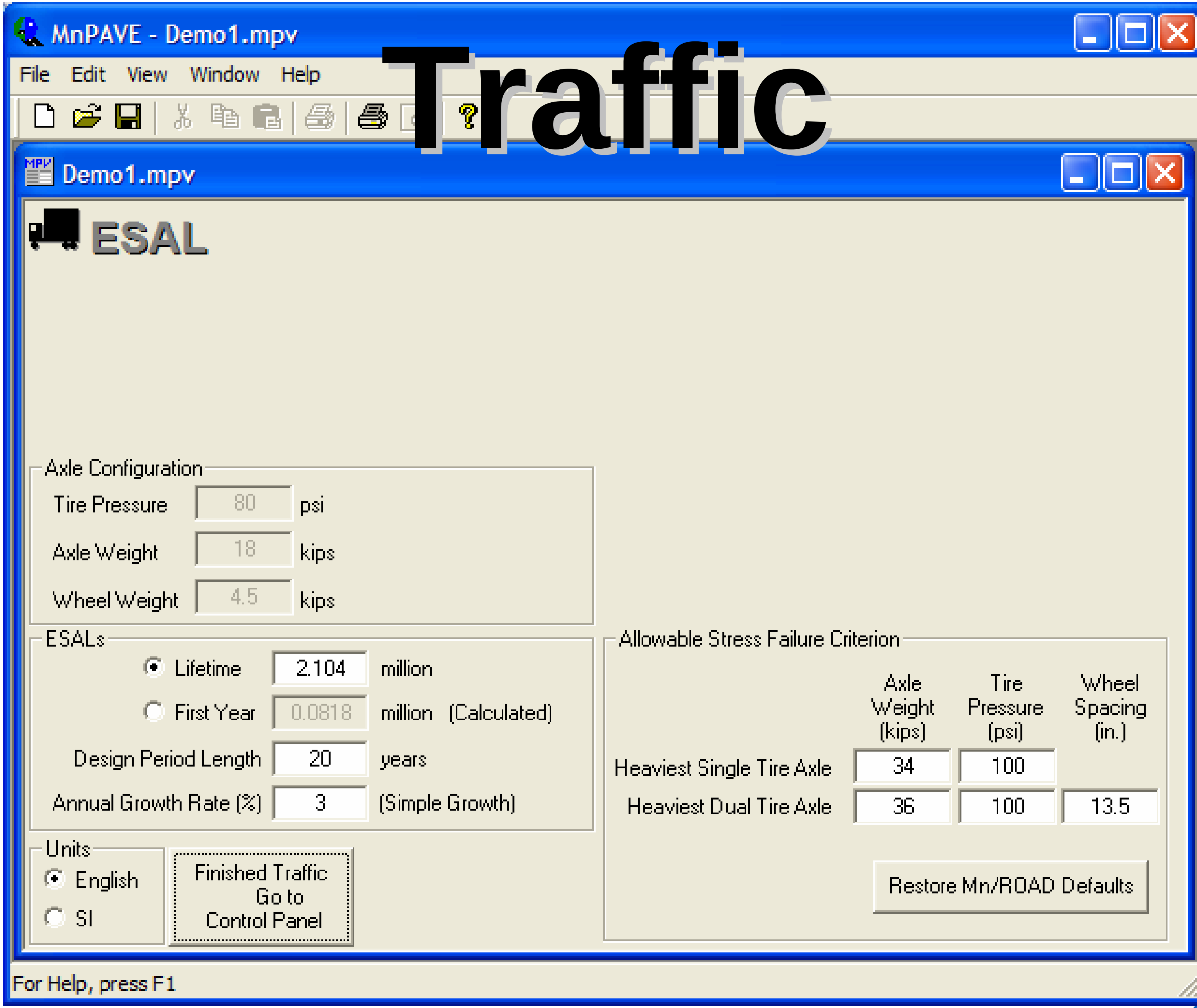
Subgrade Modulus Superimposed on Soil Map



Subgrade Modulus Predictions



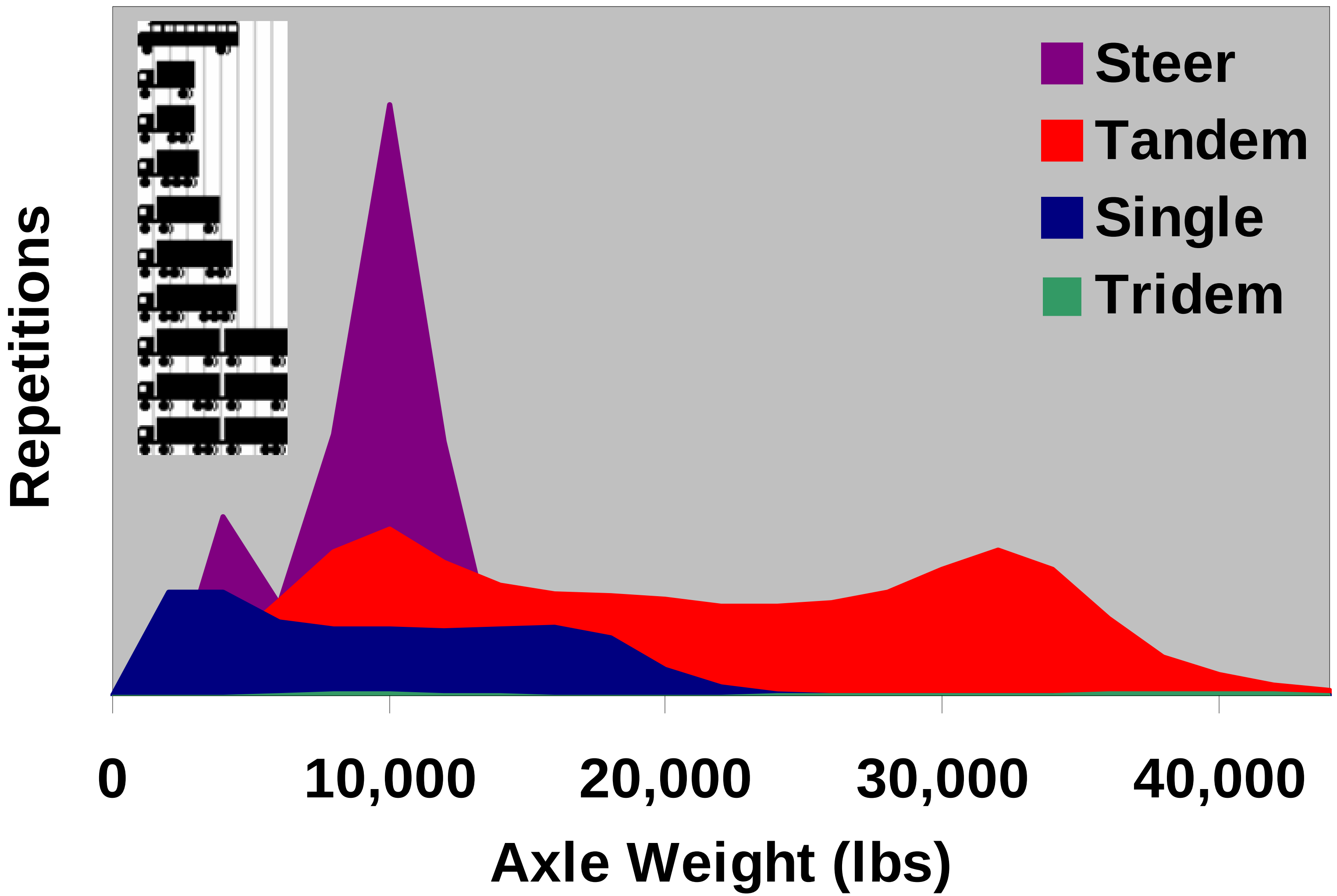
Traffic


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
ESAL
Axle Configuration
Tire Pressure 80 psi
Axle Weight 18 kips
Wheel Weight 4.5 kips
ESALs
Lifetime 2.104 million
First Year 0.0818 million (Calculated)
Design Period Length 20 years
Annual Growth Rate (%) 3 (Simple Growth)
Units
English
SI
Finished Traffic Go to Control Panel
Allowable Stress Failure Criterion
Axle Weight (kips)
Tire Pressure (psi)
Wheel Spacing (in.)
Heaviest Single Tire Axle 34 100
Heaviest Dual Tire Axle 36 100 13.5
Restore Mn/ROAD Defaults
For Help, press F1

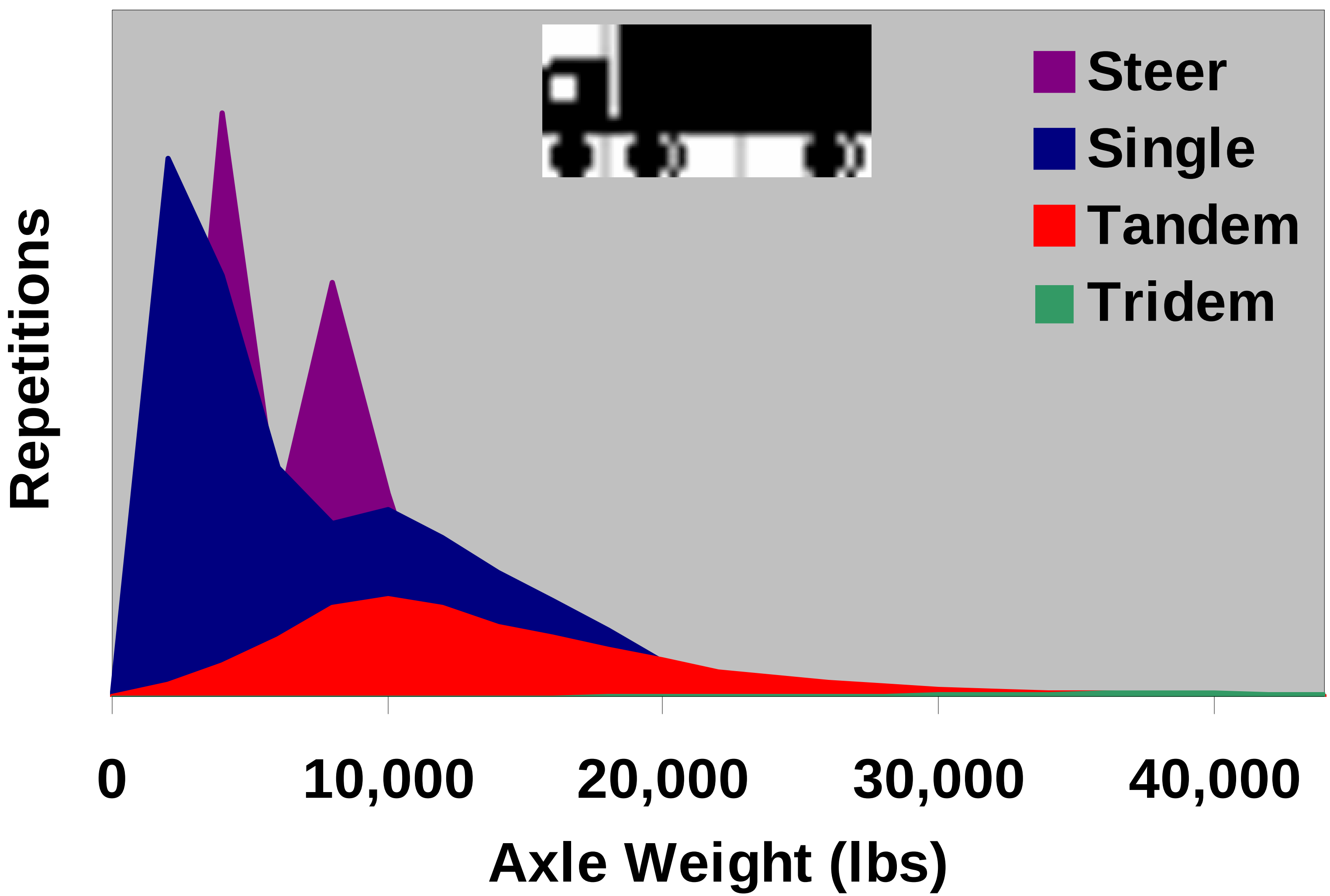
Simplified Load Spectrum Input

- Analysis of WIM data
- Mn/DOT and FHWA vehicle types
- Axle distributions by truck type
- Assumptions about truck distributions
- Route types

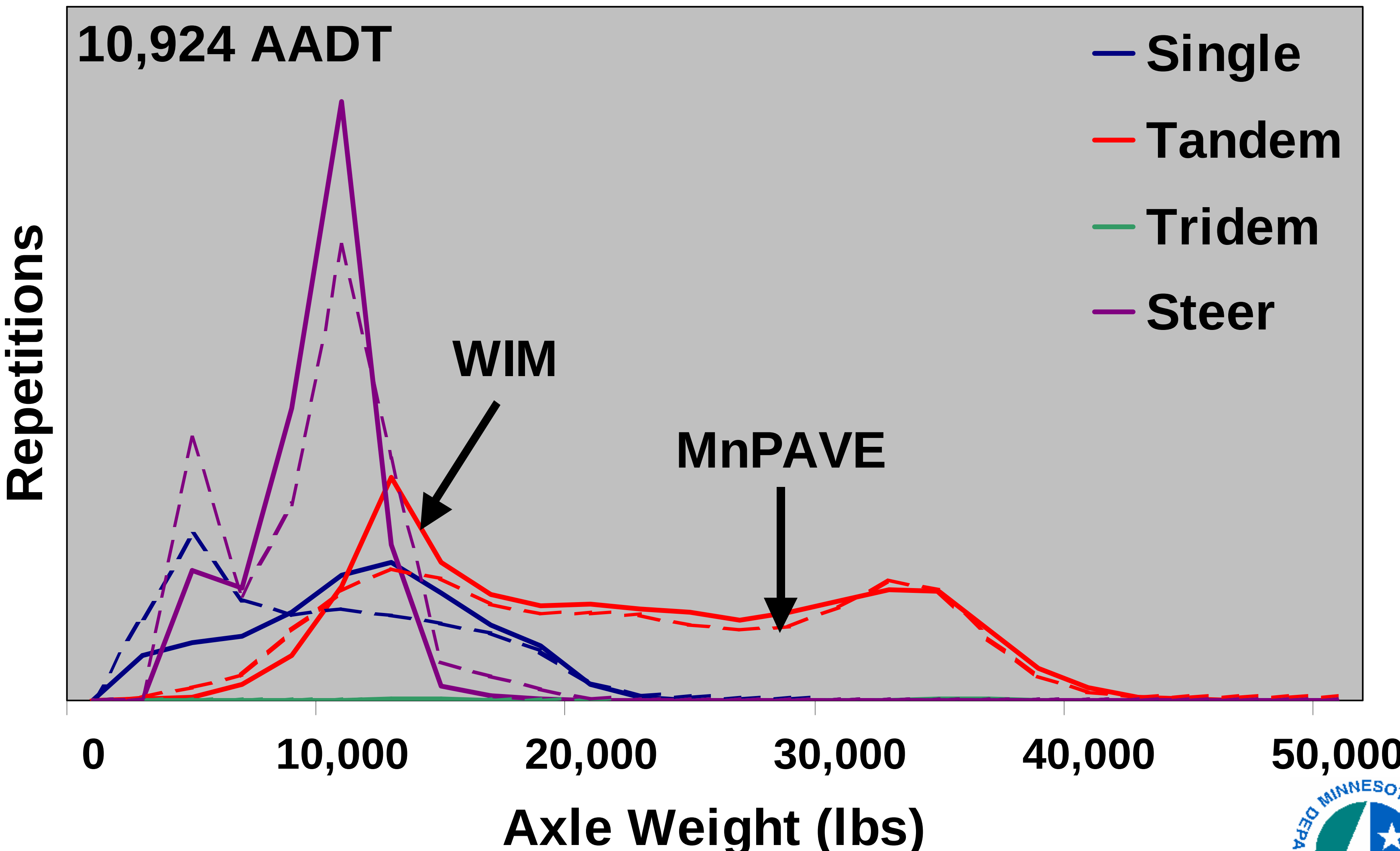
MnROAD 2001 WIM Data

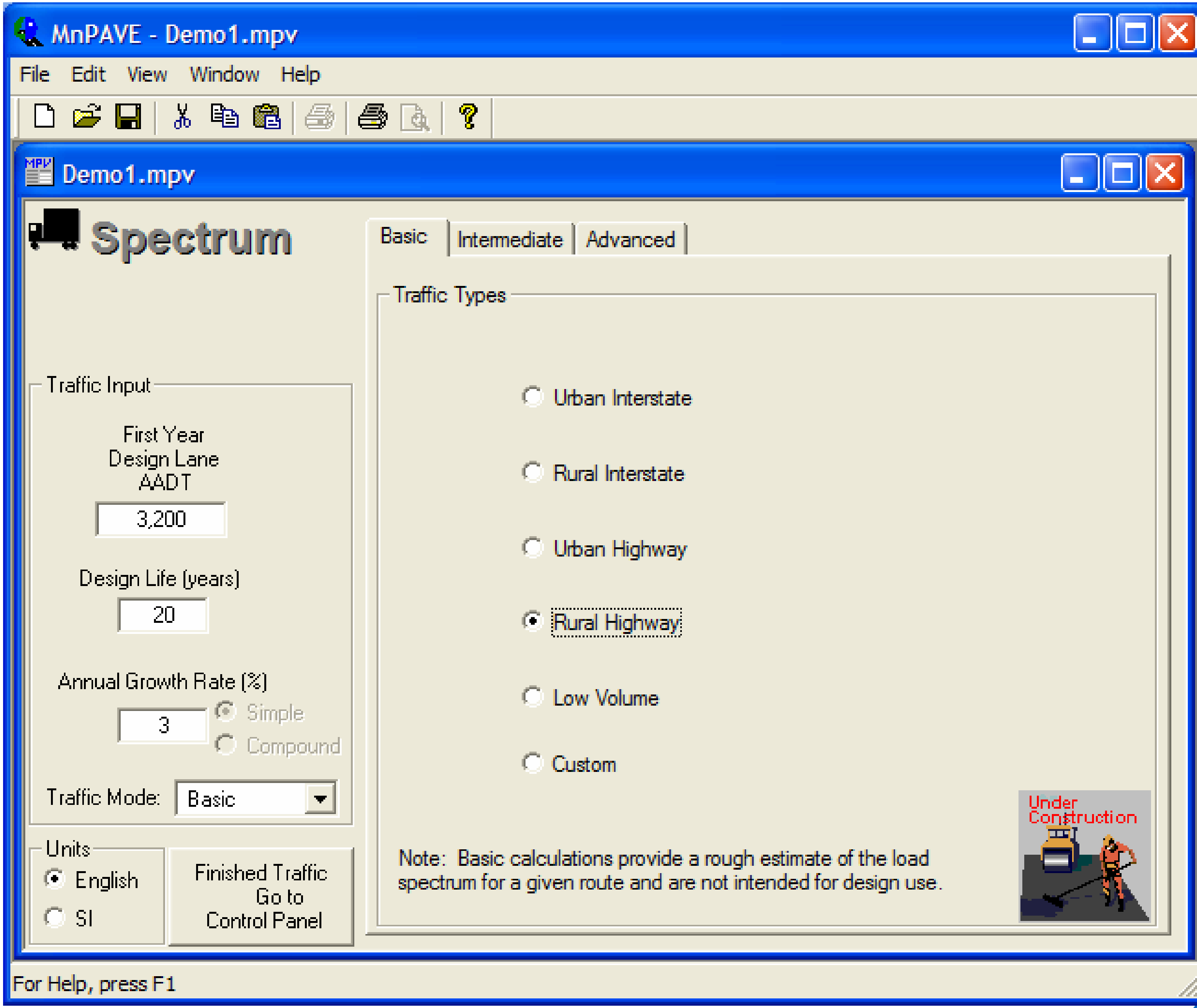


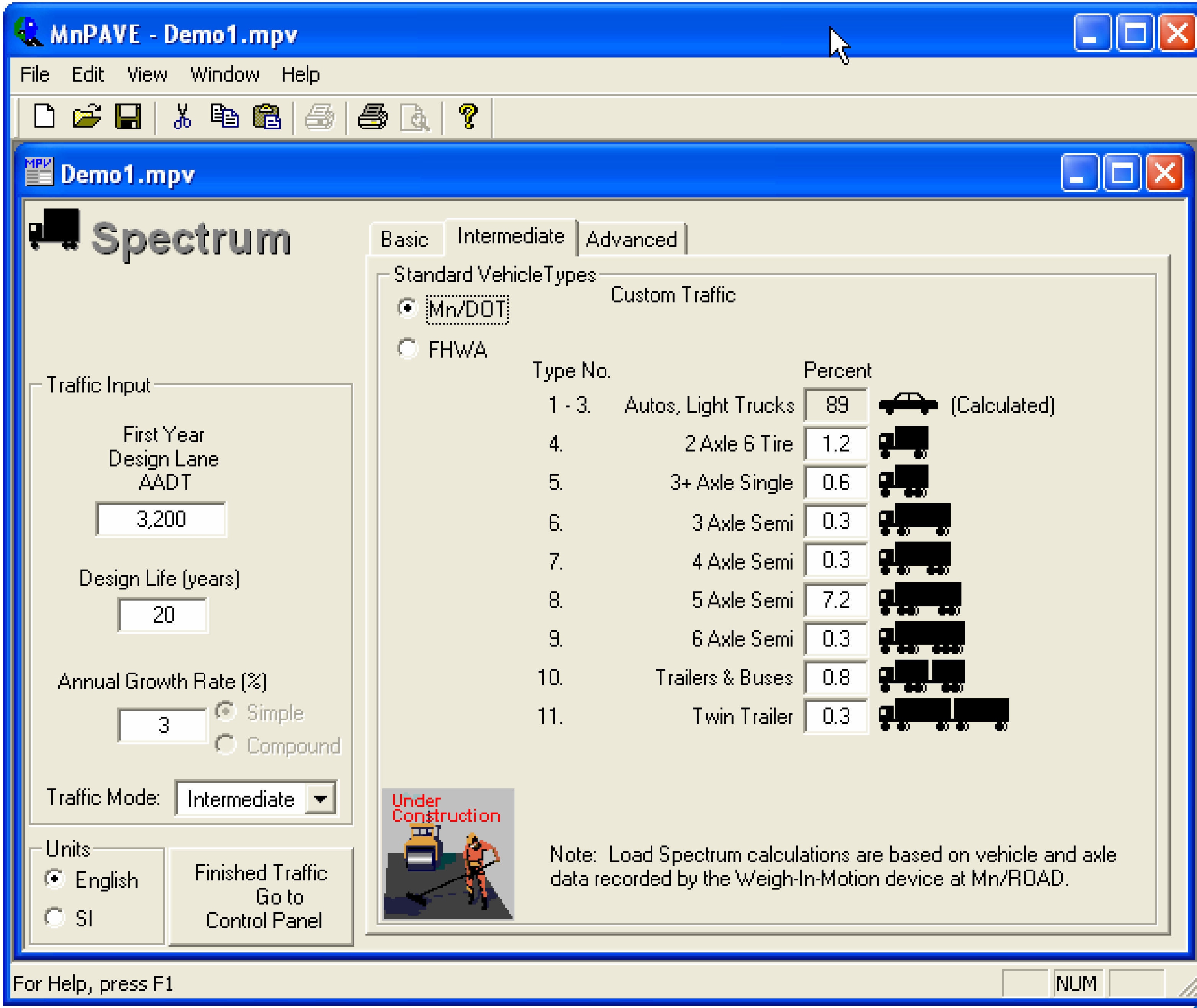
Vehicle Type 8

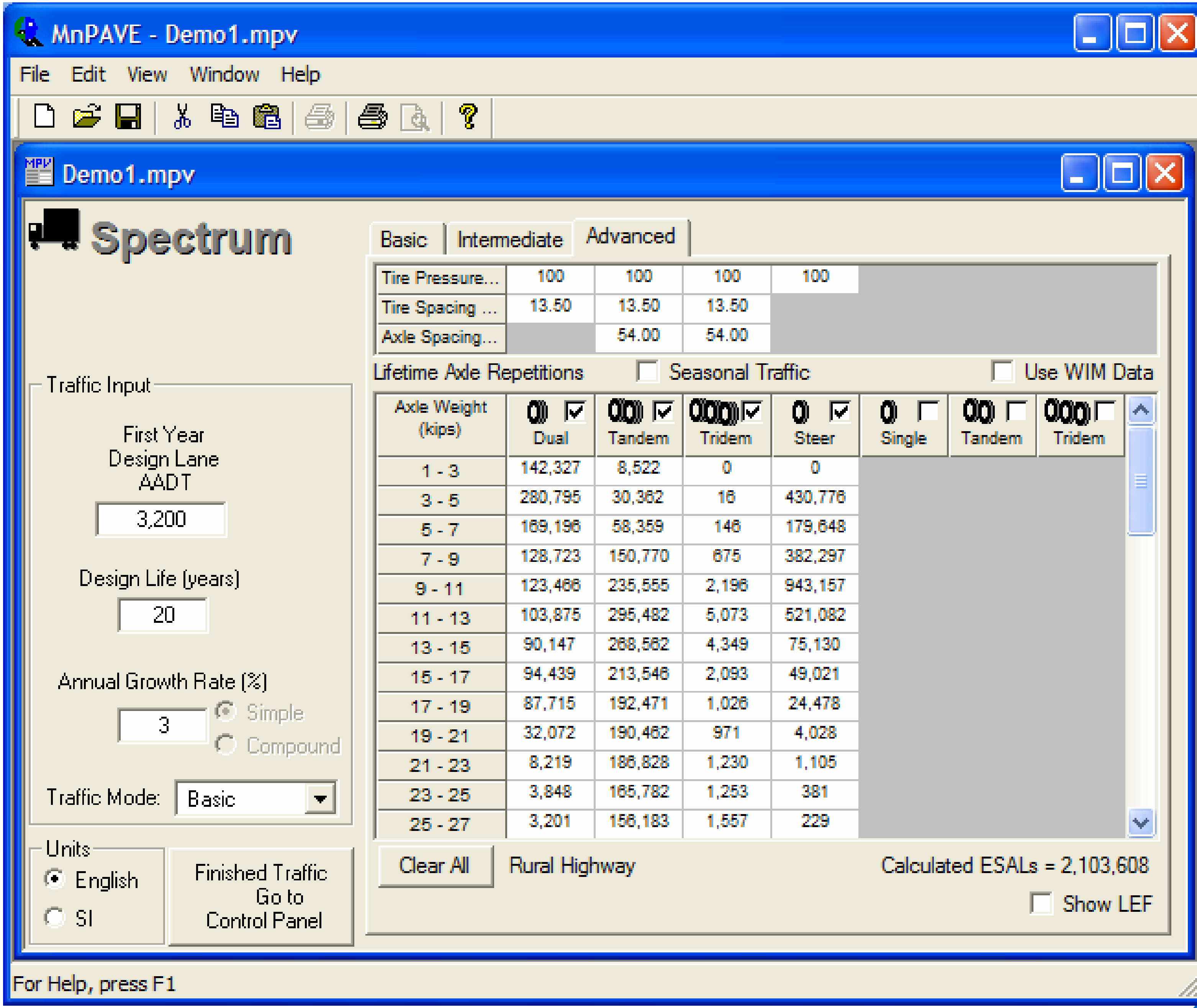


Burnsville I-35E (Feb. 1 - Mar. 1 1992)

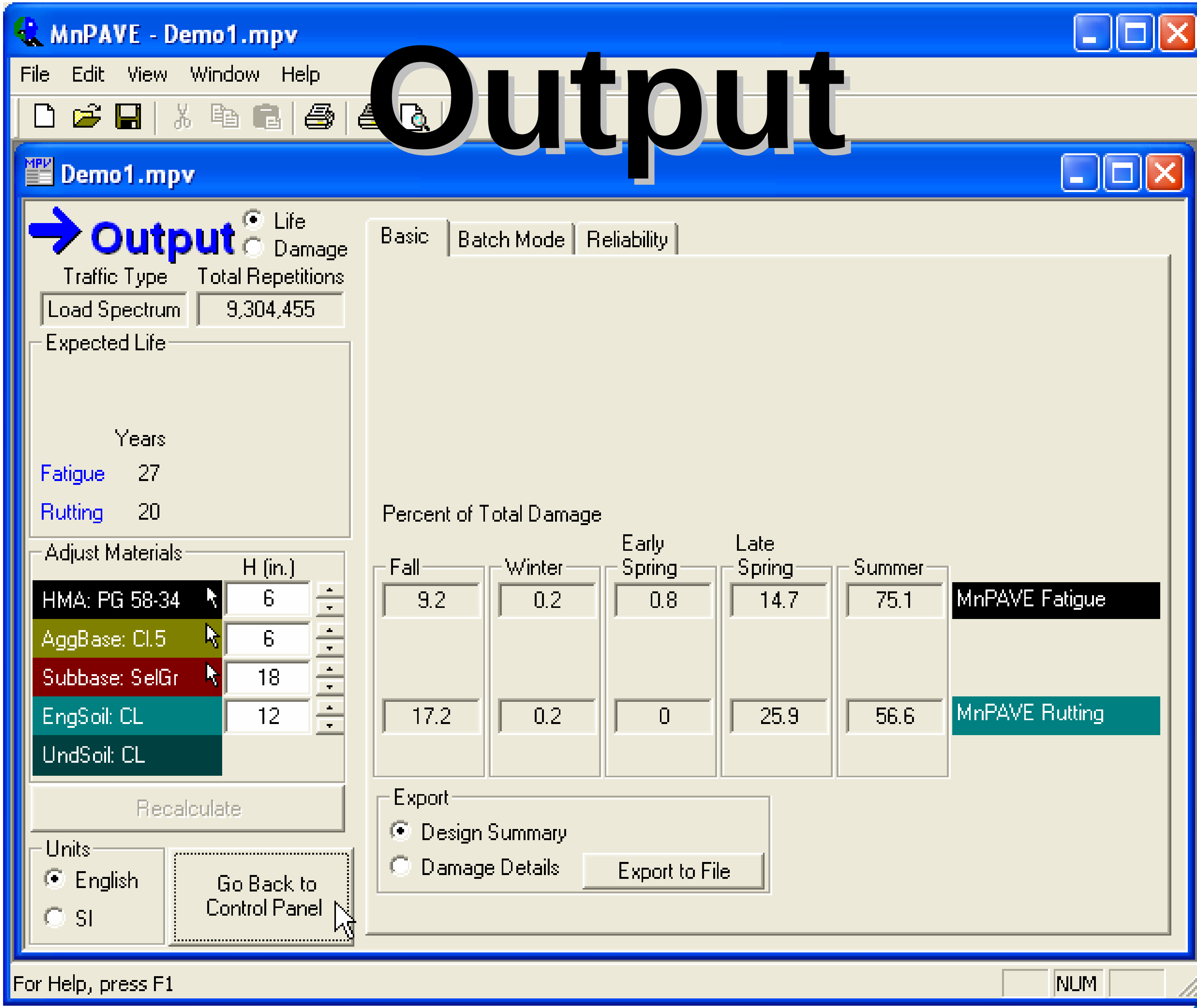



MnPAVE - Demo1.mpv
File
Edit
View
Window
Help
Demo1.mpv
Spectrum
Basic
Intermediate
Advanced
Traffic Types
Urban Interstate
Rural Interstate
Urban Highway
Rural Highway
Low Volume
Custom
Traffic Input
First Year
Design Lane
AADT
3,200
Design Life (years)
20
Annual Growth Rate (%)
3
Simple
Compound
Traffic Mode:
Basic
Units
English
SI
Finished Traffic
Go to
Control Panel
Note: Basic calculations provide a rough estimate of the load spectrum for a given route and are not intended for design use.
Under Construction
For Help, press F1


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
Spectrum
Basic
Intermediate
Advanced
Standard VehicleTypes
Mn/DOT
FHWA
Custom Traffic
Type No.
Percent
1 - 3. Autos, Light Trucks 89 (Calculated)
4. 2 Axle 6 Tire 1.2
5. 3+ Axle Single 0.6
6. 3 Axle Semi 0.3
7. 4 Axle Semi 0.3
8. 5 Axle Semi 7.2
9. 6 Axle Semi 0.3
10. Trailers & Buses 0.8
11. Twin Trailer 0.3
Under Construction
Note: Load Spectrum calculations are based on vehicle and axle data recorded by the Weigh-In-Motion device at Mn/ROAD.
Traffic Input
First Year Design Lane AADT
3,200
Design Life (years)
20
Annual Growth Rate (%)
3
Simple
Compound
Traffic Mode: Intermediate
Units
English
SI
Finished Traffic Go to Control Panel
For Help, press F1
NUM


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
Spectrum
Basic
Intermediate
Advanced
Tire Pressure... 100 100 100 100
Tire Spacing ... 13.50 13.50 13.50
Axle Spacing... 54.00 54.00
Lifetime Axle Repetitions
Seasonal Traffic
Use WIM Data
Axle Weight (kips)
Dual
Tandem
Tridem
Steer
Single
Tandem
Tridem
1 - 3 142,327 8,522 0 0
3 - 5 280,795 30,362 16 430,776
5 - 7 169,196 58,359 146 179,648
7 - 9 128,723 150,770 675 382,297
9 - 11 123,466 235,555 2,196 943,157
11 - 13 103,875 295,482 5,073 521,082
13 - 15 90,147 268,562 4,349 75,130
15 - 17 94,439 213,546 2,093 49,021
17 - 19 87,715 192,471 1,026 24,478
19 - 21 32,072 190,462 971 4,028
21 - 23 8,219 186,828 1,230 1,105
23 - 25 3,848 165,782 1,253 381
25 - 27 3,201 156,183 1,557 229
Traffic Input
First Year Design Lane AADT
3,200
Design Life (years)
20
Annual Growth Rate (%)
3
Simple
Compound
Traffic Mode:
Basic
Units
English
SI
Finished Traffic Go to Control Panel
Clear All
Rural Highway
Calculated ESALs = 2,103,608
Show LEF
For Help, press F1

Output


MnPAVE - Demo1.mpv
File Edit View Window Help
Demo1.mpv
Output
Life
Damage
Traffic Type
Total Repetitions
Load Spectrum
9,304,455
Expected Life
Years
Fatigue 27
Rutting 20
Adjust Materials
H (in.)
HMA: PG 58-34 6
AggBase: Cl.5 6
Subbase: SelGr 18
EngSoil: CL 12
UndSoil: CL
Recalculate
Units
English
SI
Go Back to Control Panel
Basic
Batch Mode
Reliability
Percent of Total Damage
Fall
Winter
Early Spring
Late Spring
Summer
9.2 0.2 0.8 14.7 75.1 MnPAVE Fatigue
17.2 0.2 0 25.9 56.6 MnPAVE Rutting
Export
Design Summary
Damage Details
Export to File
For Help, press F1
NUM

Questions

www.mrr.dot.state.mn.us