



Mn/DOT Flexible Pavement Design Mechanistic-Empirical Method

**Pavement Design Systems and Pavement Performance Models
March 22-23, 2007 - Reykjavik, Iceland**

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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



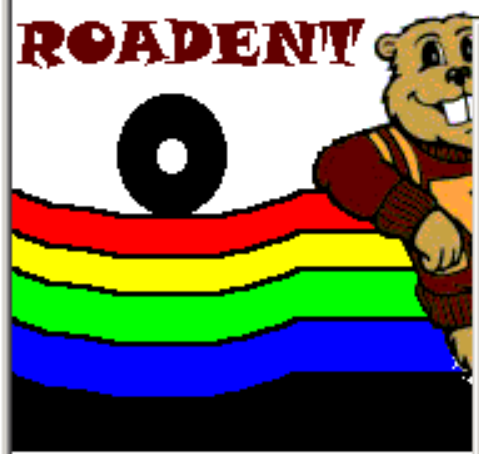
University of Minnesota (1996-1999)

Dr. David Timm – Auburn University

Dr. David Newcomb – NAPA

Dr. Bjorn Birgisson – University of Florida





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

 Climate

 Structure

 Traffic

 Output

For Help, press F1

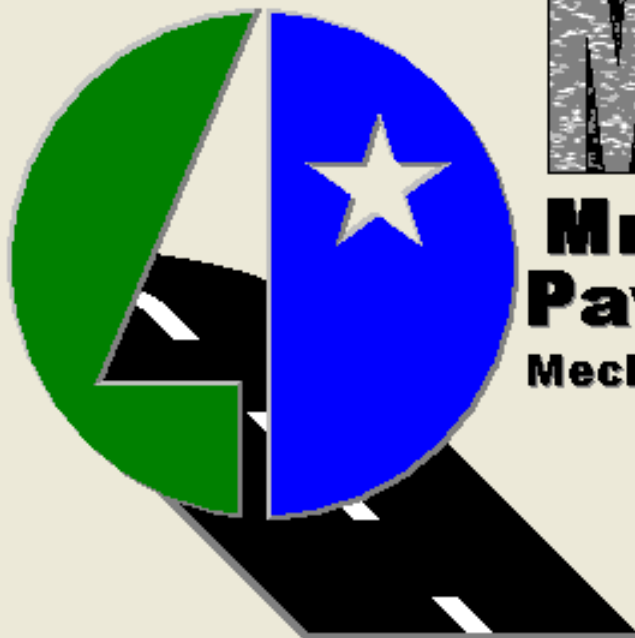


MnPAVE - MnPAVE1

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".




 **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



Seasons
Ramsey County

	<input checked="" type="radio"/> Days	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

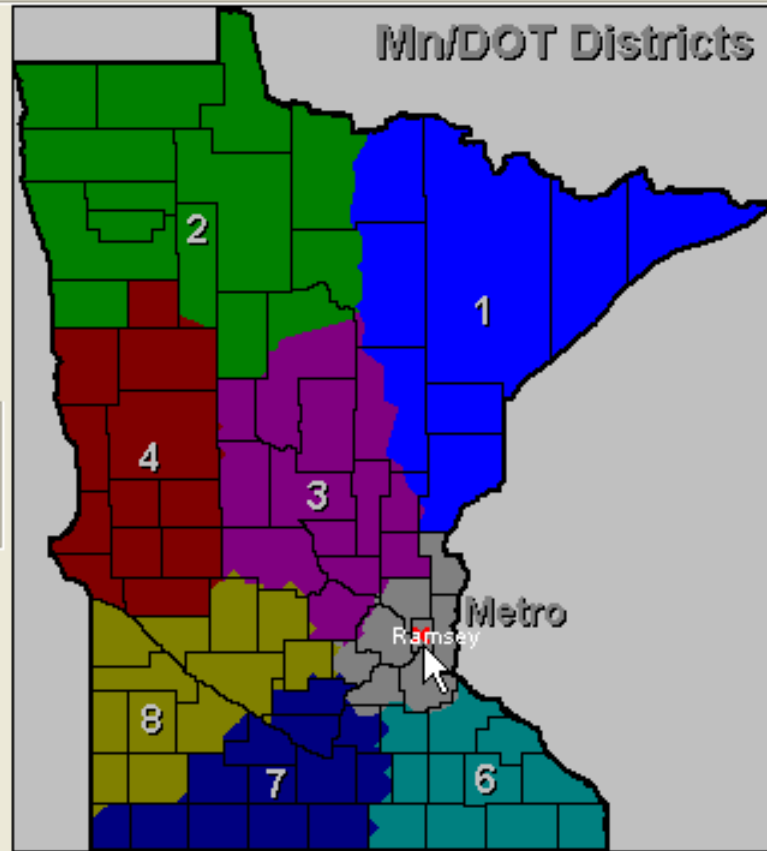
45 ° 0

Longitude

93 ° 6

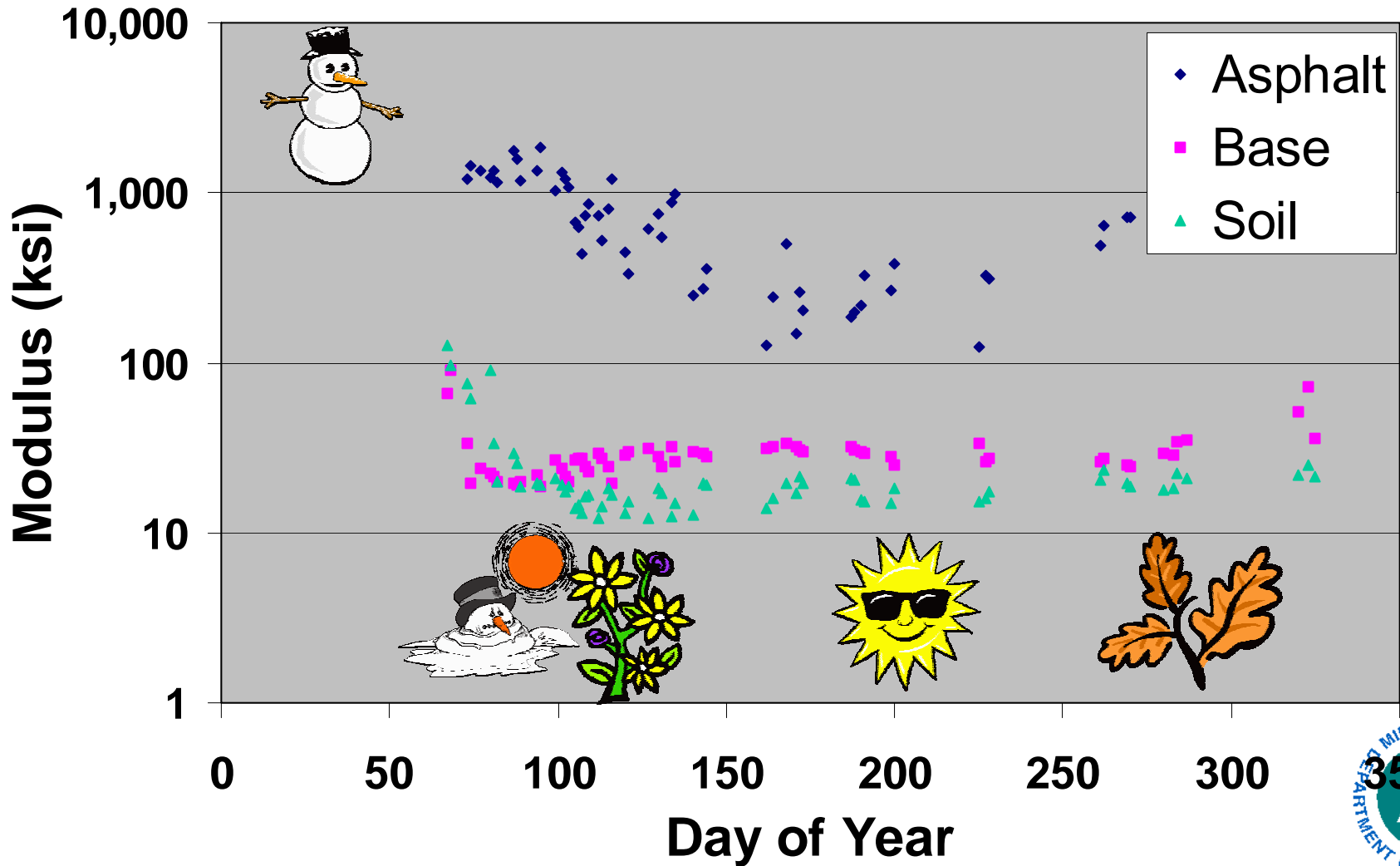
Pointer Text

- Counties
- Coordinates
- None



Seasons

MnROAD Cell 21



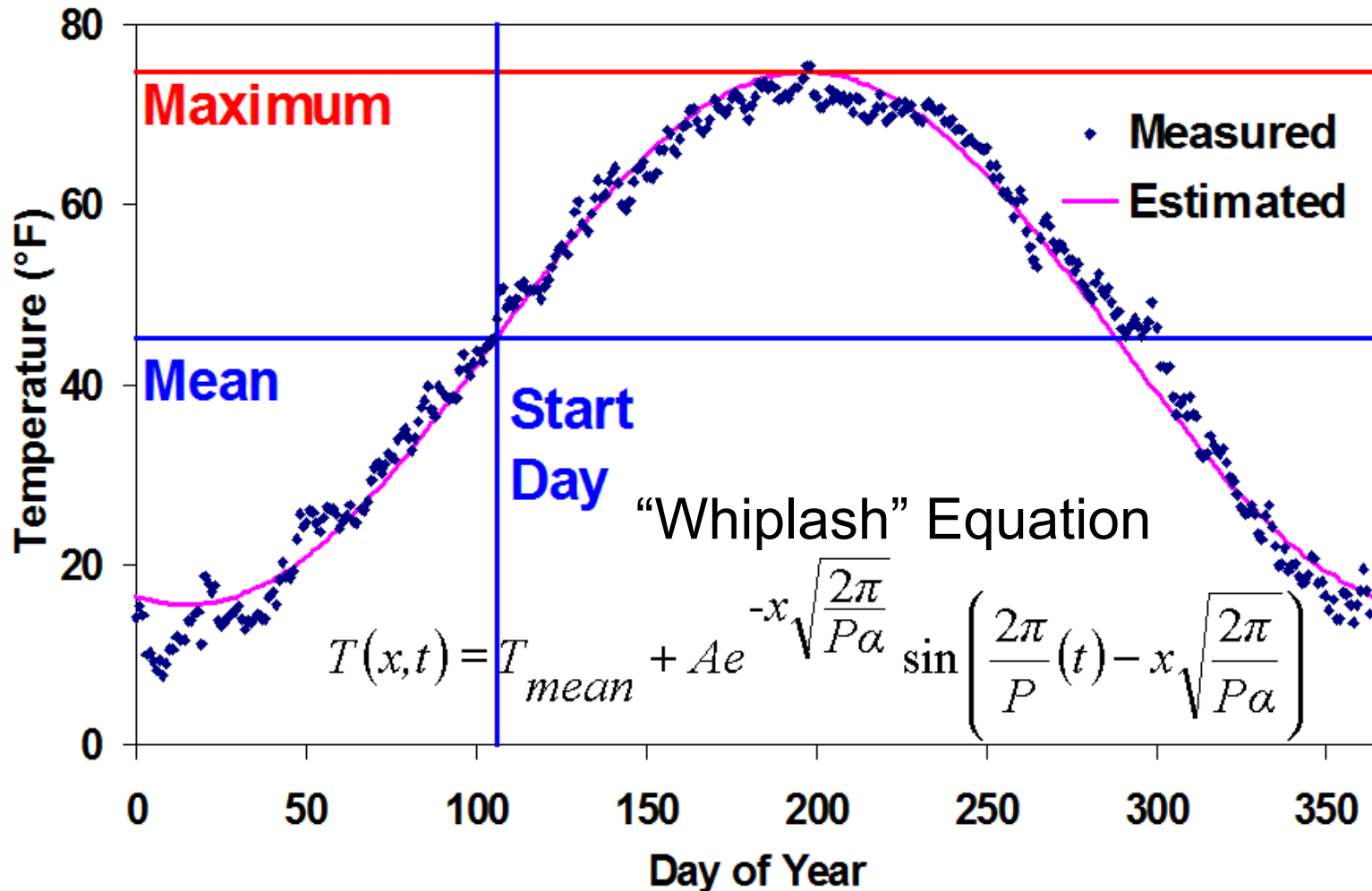
Criteria for Determining the Beginning of MnPAVE Seasons

Season	Criteria
Fall	3-day Average Temperature $< 17\text{ }^{\circ}\text{C}$
Winter	Freezing Index $> 90\text{ }^{\circ}\text{C-days}$
Spring Thaw	Thawing Index $> 15\text{ }^{\circ}\text{C-days}$
Spring Recovery	2 Weeks After Start of Spring Thaw
Summer	3-day Average Temperature $> 17\text{ }^{\circ}\text{C}$

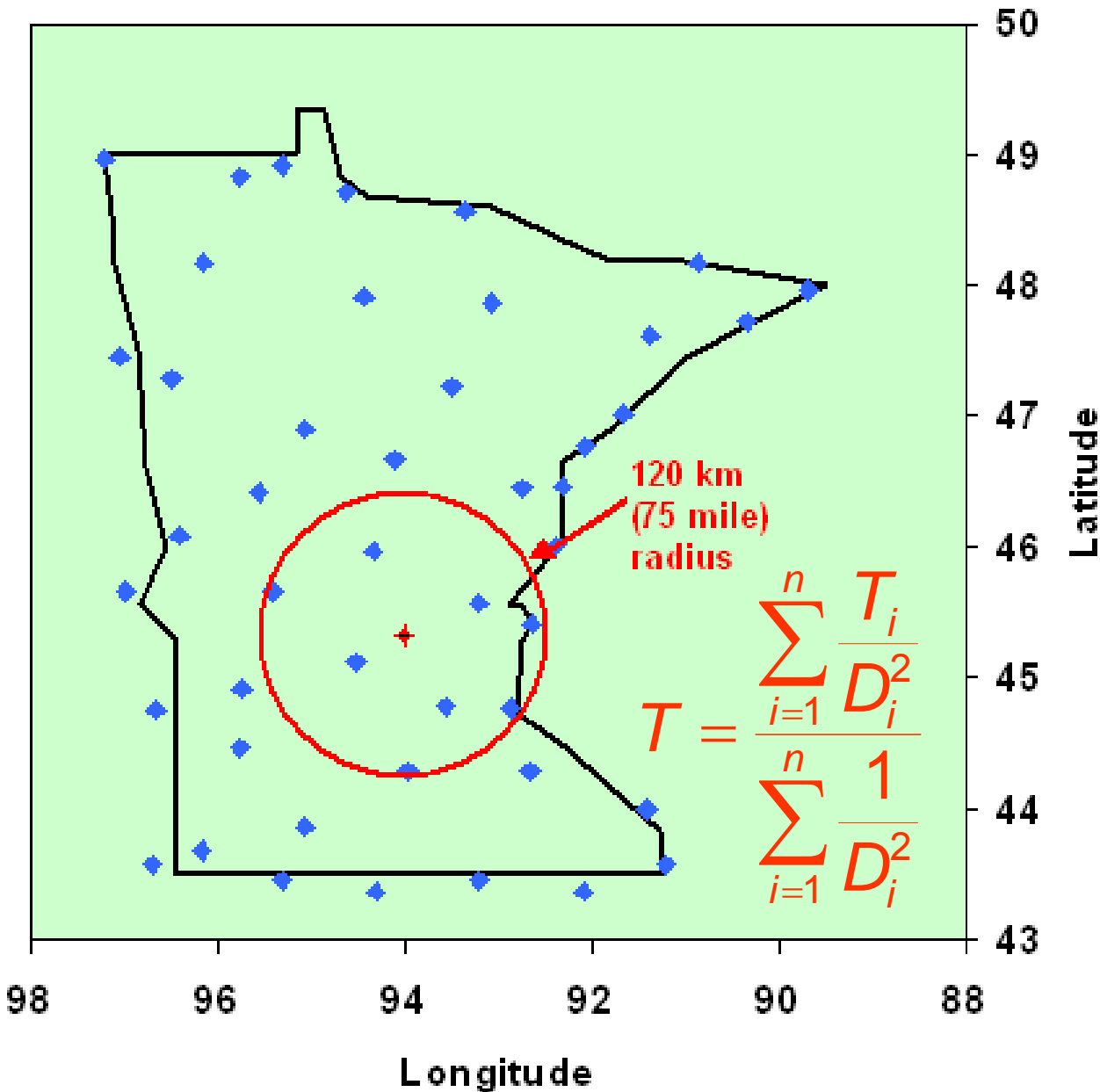


Temperature Model

30-Year Average Daily Temperatures (1971 - 2000)
Marshall, MN



Weather Stations



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 Help

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.)
<input type="radio"/> 1	HMA	6
<input type="radio"/> 2	AggBase	6
<input type="radio"/> 3	Subbase	18
<input type="radio"/> 4	EngSoil	12
<input checked="" type="radio"/> 5	UndSoil	

Design Mode: Basic

Units
 English
 SI

Finished Structure
Go to Control Panel

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

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

Edit Structure

Layers	Material	Thickness (in.)
<input type="radio"/> 1	HMA	6
<input type="radio"/> 2	AggBase	6
<input type="radio"/> 3	Subbase	18
<input type="radio"/> 4	EngSoil	12
<input checked="" type="radio"/> 5	UndSoil	

Design Mode: Intermediate

Units
 English
 SI

Finished Structure
 Go to Control Panel

PG 58-34

22

11

15
CL

Moisture Data

Mohr-Coulomb

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.)
<input type="radio"/> 1	HMA	6
<input type="radio"/> 2	AggBase	6
<input type="radio"/> 3	Subbase	18
<input type="radio"/> 4	EngSoil	12
<input checked="" type="radio"/> 5	UndSoil	

Design Mode: **Advanced**

Units

- English
- SI

Finished Structure
Go to Control Panel

	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

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)

$f =$ Load frequency (Hz)

$\eta = 10^{-8}$ x Dynamic Viscosity (cP)

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

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

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

$V_a =$ Air voids (% by volume)

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

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

$p_4 =$ Cumulative % retained on No. 4 sieve

$G_b =$ specific gravity of binder

$p_{200} =$ Percent passing No. 200 sieve

$G_{sb} =$ Bulk specific gravity of aggregate



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)

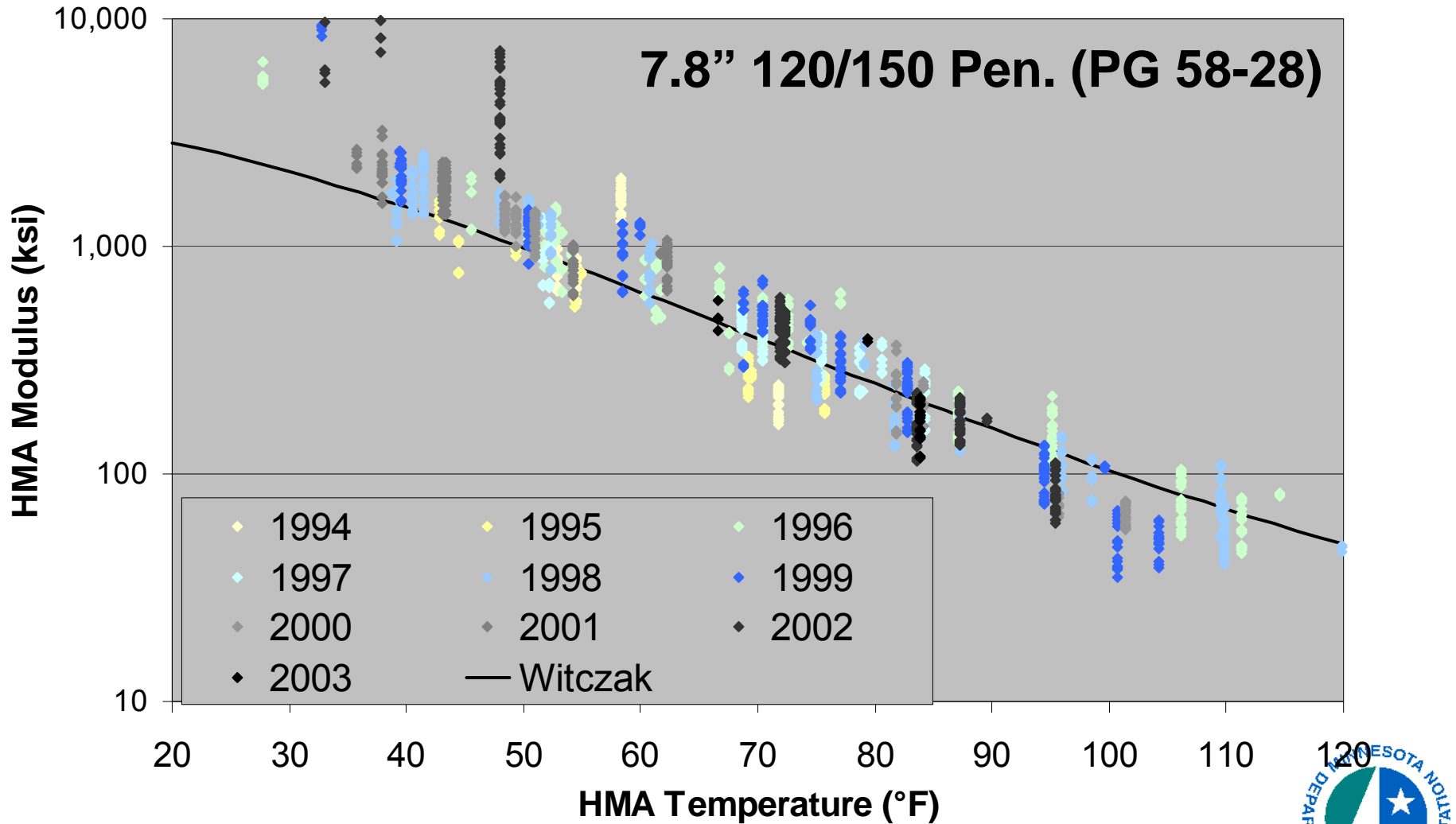
D_1 = Deflection at 12 in. (305 mm) from center of load

D_2 = Deflection at 24 in. (610 mm) from center of load

D_3 = Deflection at 36 in. (914 mm) from center of load



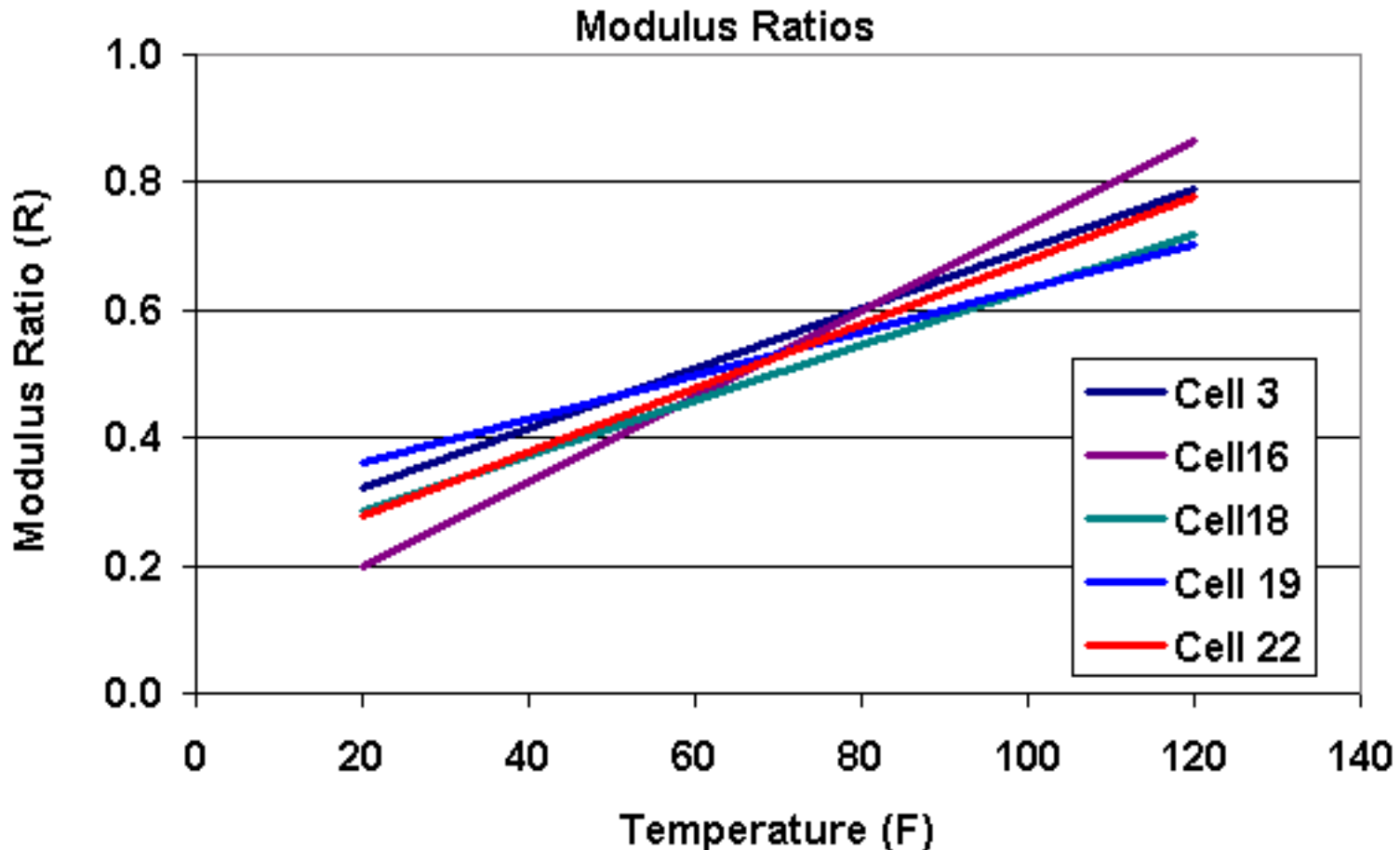
Cell 20 Modulus Comparison 1994-2003 Witczak and Thompson Equations



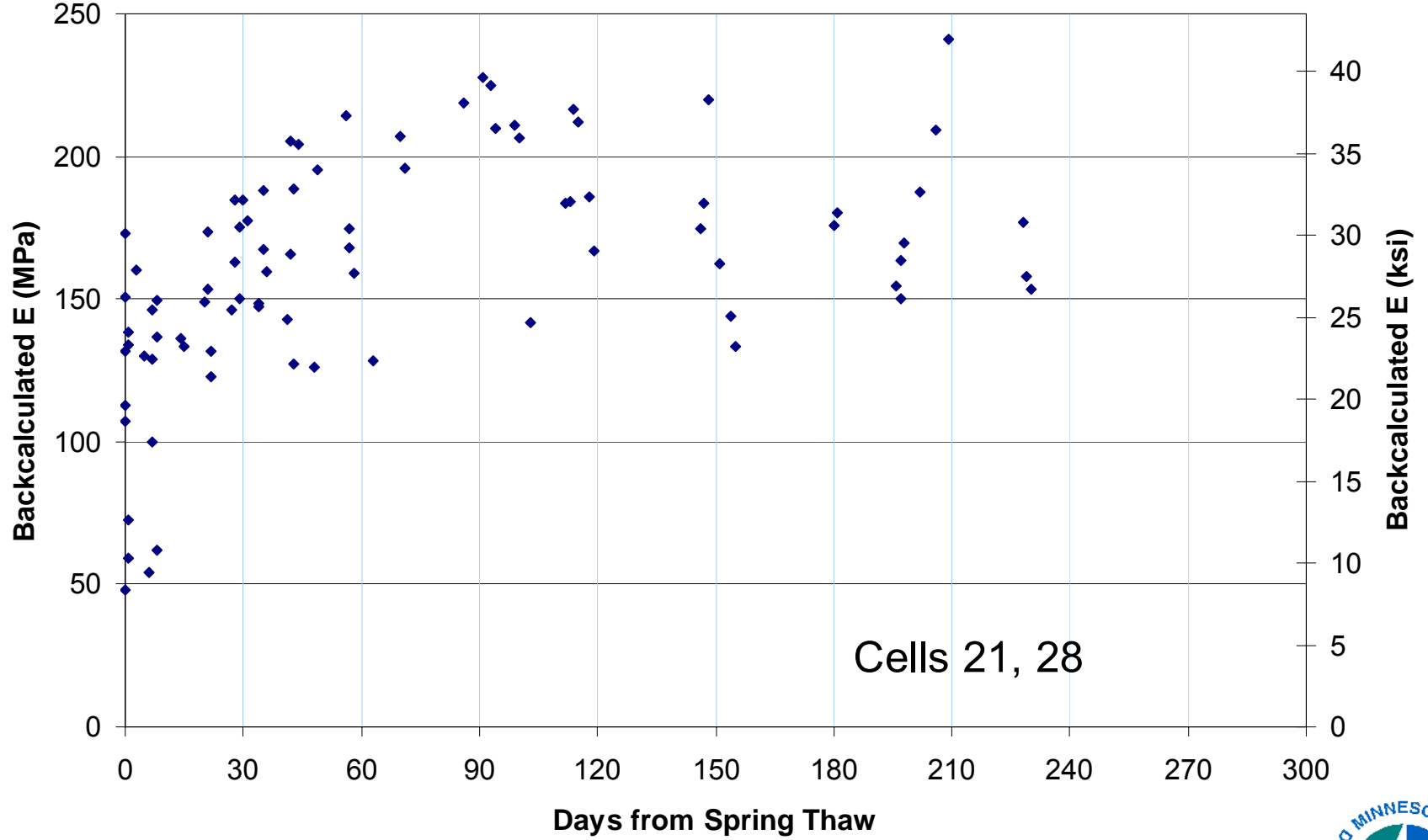
Modulus Reduction Factor

– Modulus Ratio (R)

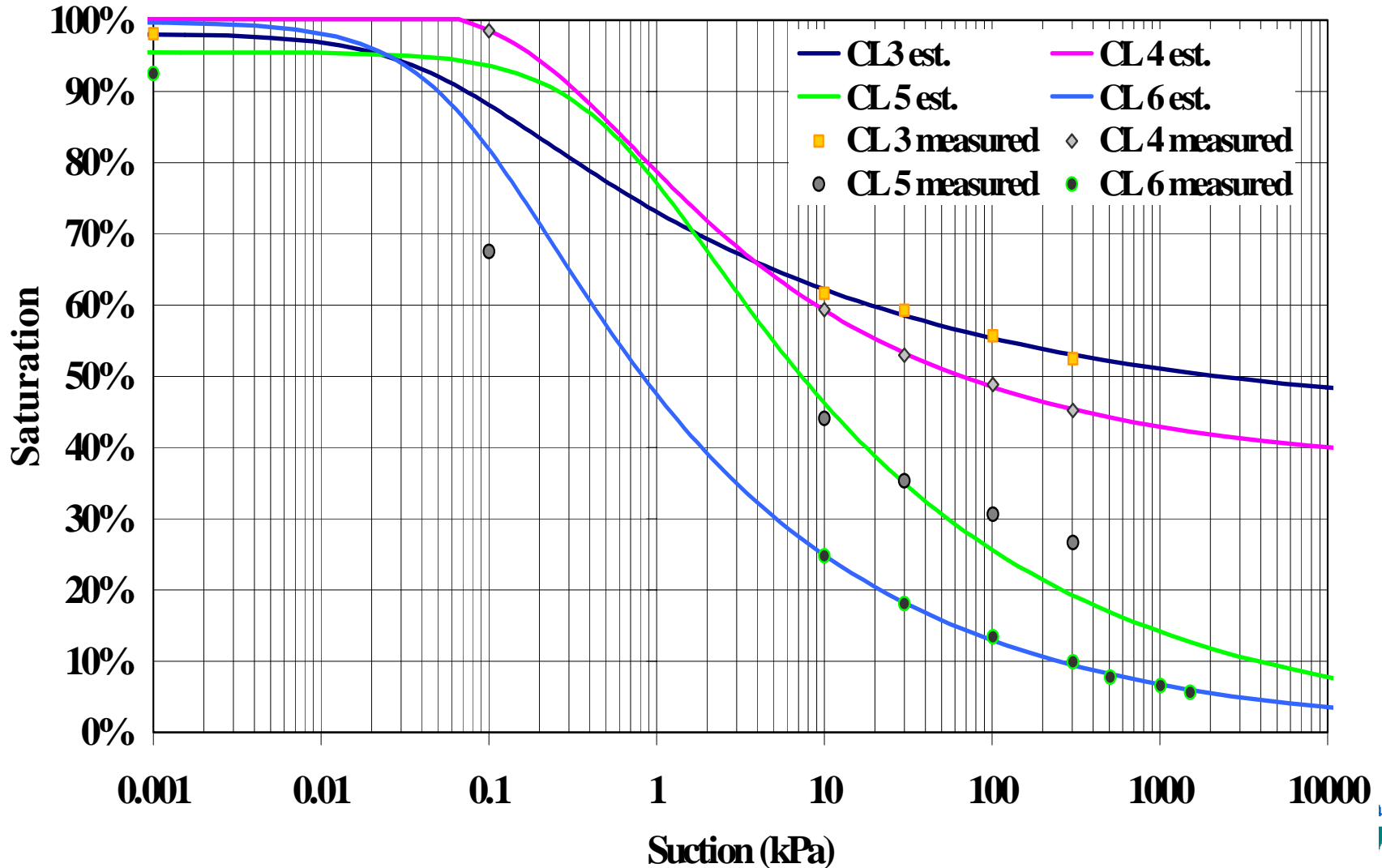
- $R = E^*(\text{near crack}) / E^*(\text{between cracks})$



MnROAD Class 5 Moduli 1994-1996



Unsaturated Properties



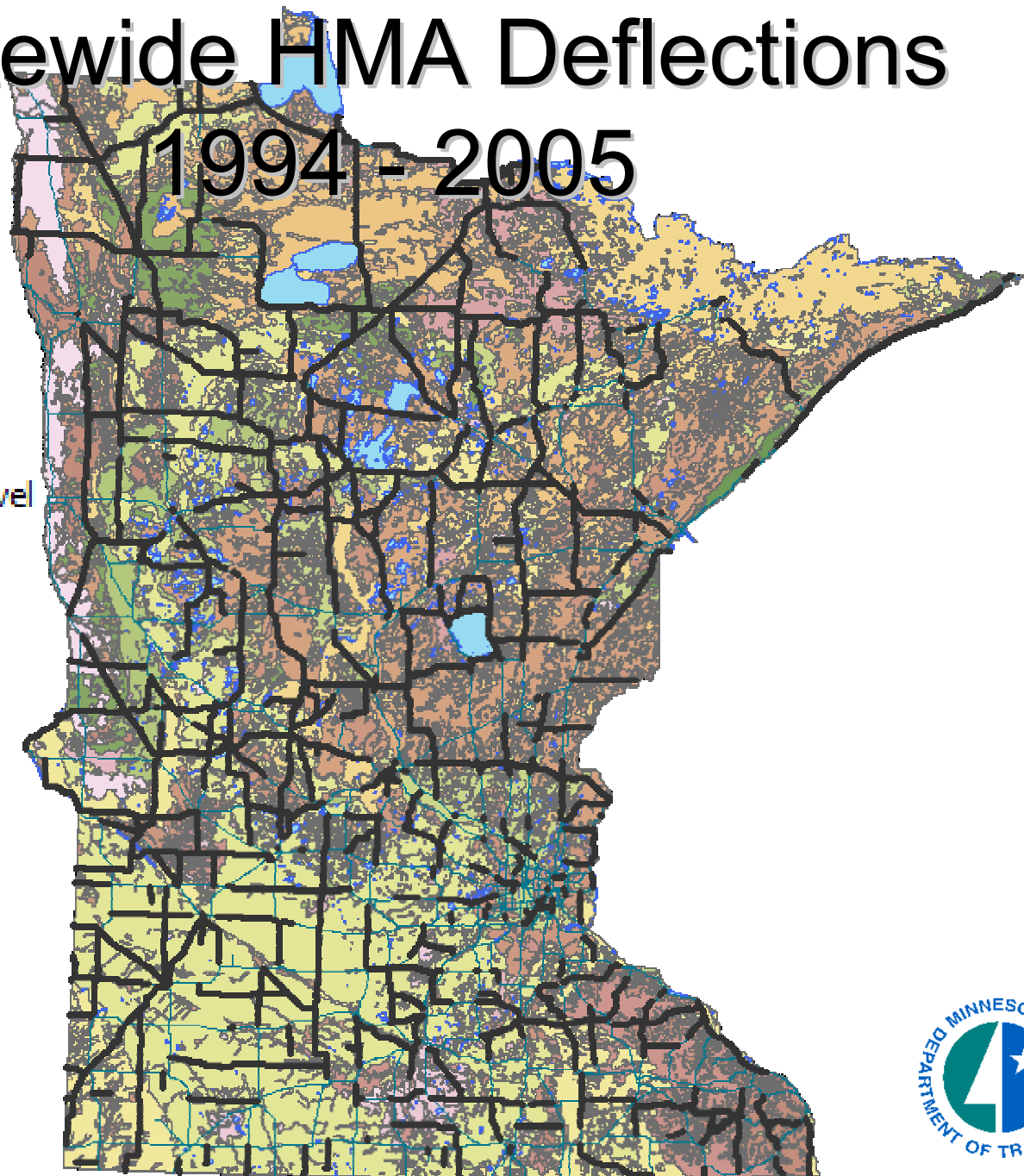
Soil Class

LEGEND

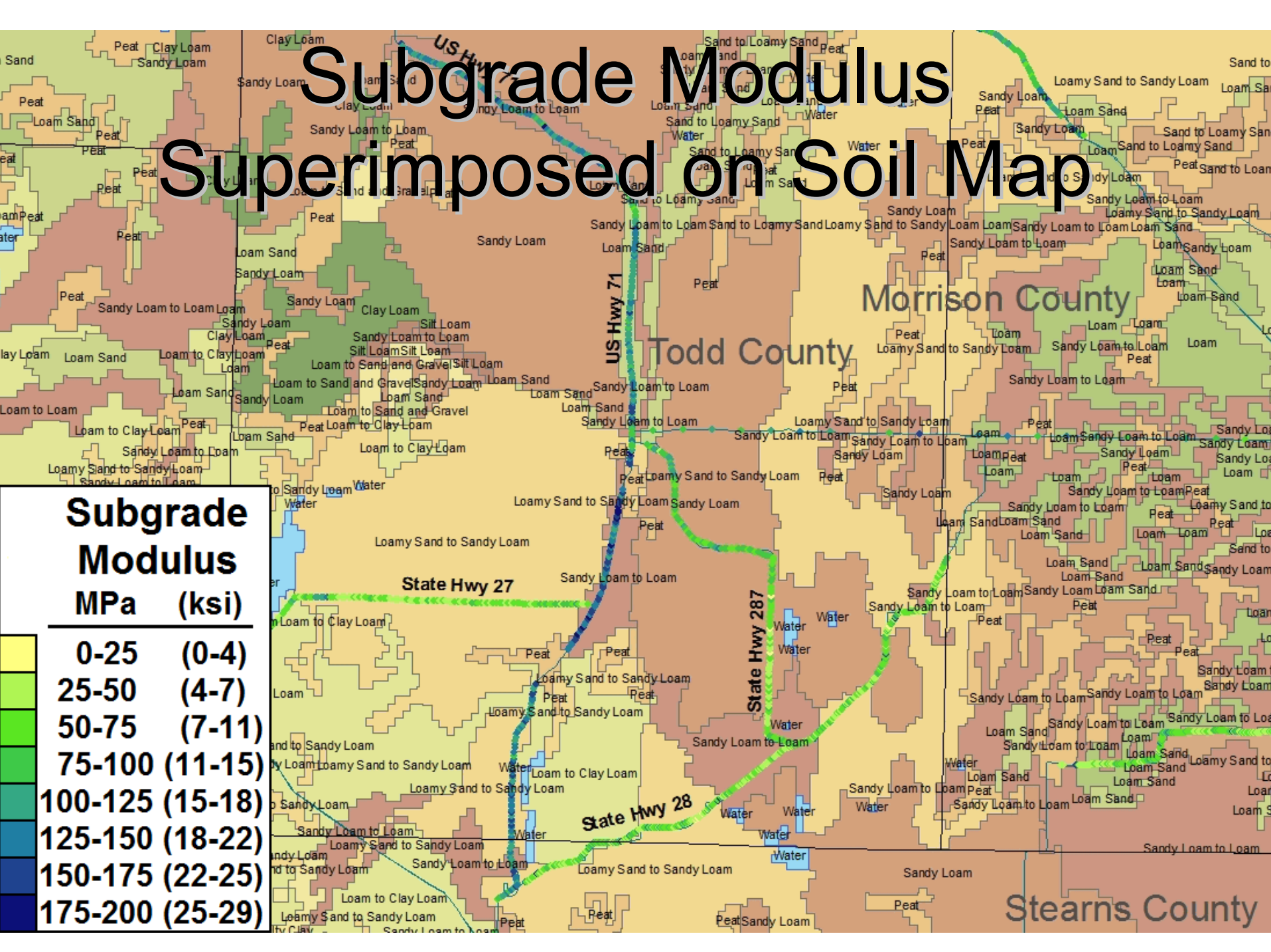
- Clay
- Clay Loam
- Clay Loam to Silty Clay Loam
- Loam
- Loam Sand
- Loam to Clay Loam
- Loam to Sand and Gravel
- Loam to Silt Loam
- Loam to Silty Clay
- Loam, Clay Loam, Sand and Gravel
- Loamy Sand to Sandy Loam
- Mine Dumps
- Peat
- Sand
- Sand to Loamy Sand
- Sandy Loam
- Sandy Loam to Loam
- Silt Loam
- Silt Loam to Silty Clay Loam
- Silty Clay
- Silty Clay Loam
- Silty Clay Loam to Silty Clay
- Silty Clay to Clay
- Water

Statewide HMA Deflections

1994 - 2005



Subgrade Modulus Superimposed on Soil Map



Subgrade Modulus

MPa (ksi)

0-25 (0-4)

25-50 (4-7)

50-75 (7-11)

75-100 (11-15)

100-125 (15-18)

125-150 (18-22)

150-175 (22-25)

175-200 (25-29)

Morrison County

Todd County

Stearns County

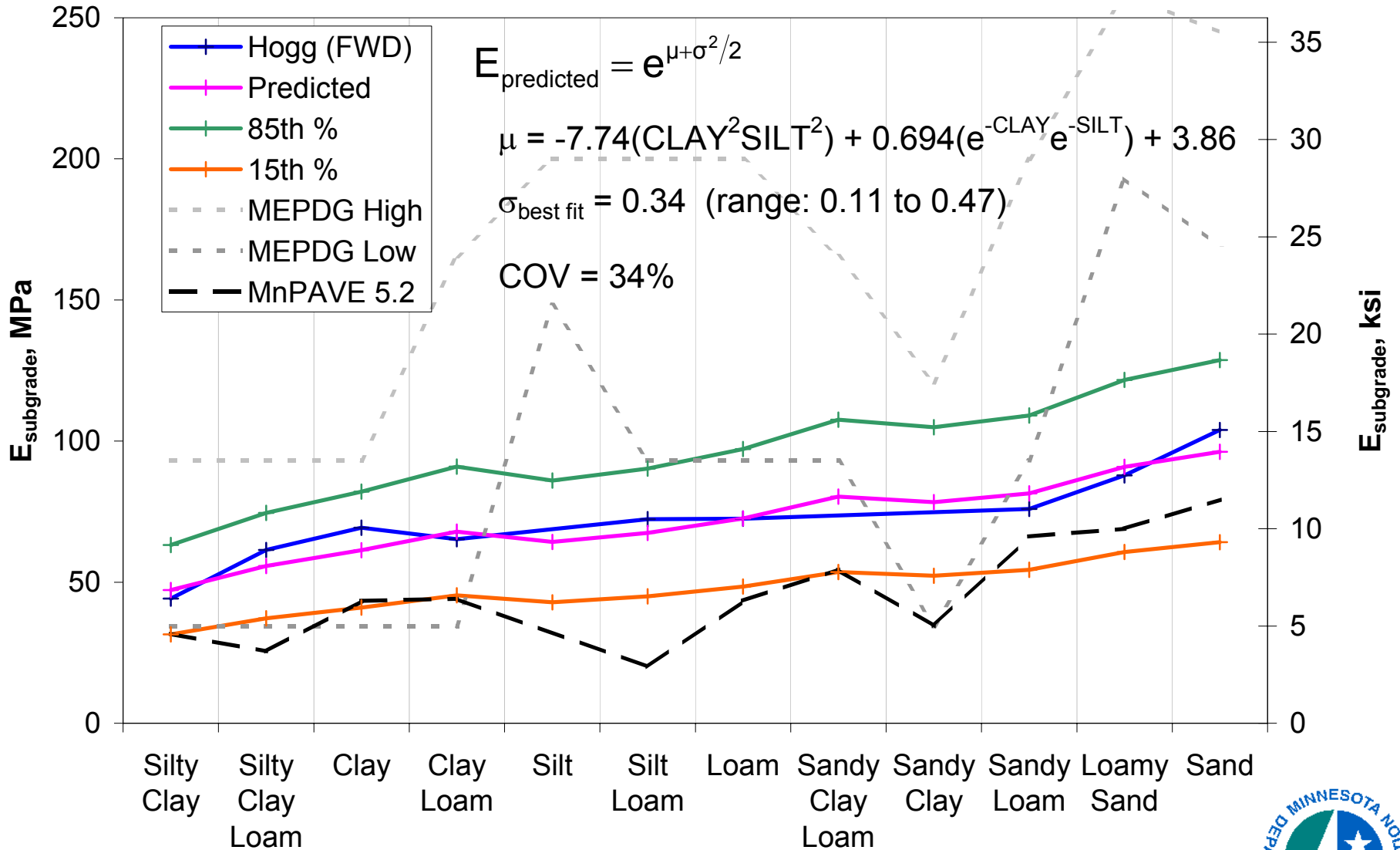
US Hwy 71

State Hwy 27

State Hwy 287

State Hwy 28

Subgrade Modulus Predictions



Traffic

MnPAVE - Demo1.mpv

File Edit View Window Help

Demo1.mpv

ESAL

Axle Configuration

Tire Pressure psi

Axle Weight kips

Wheel Weight kips

ESALs

Lifetime million

First Year million (Calculated)

Design Period Length years

Annual Growth Rate (%) (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	<input type="text" value="34"/>	<input type="text" value="100"/>	
Heaviest Dual Tire Axle	<input type="text" value="36"/>	<input type="text" value="100"/>	<input type="text" value="13.5"/>

Restore Mn/ROAD Defaults

For Help, press F1

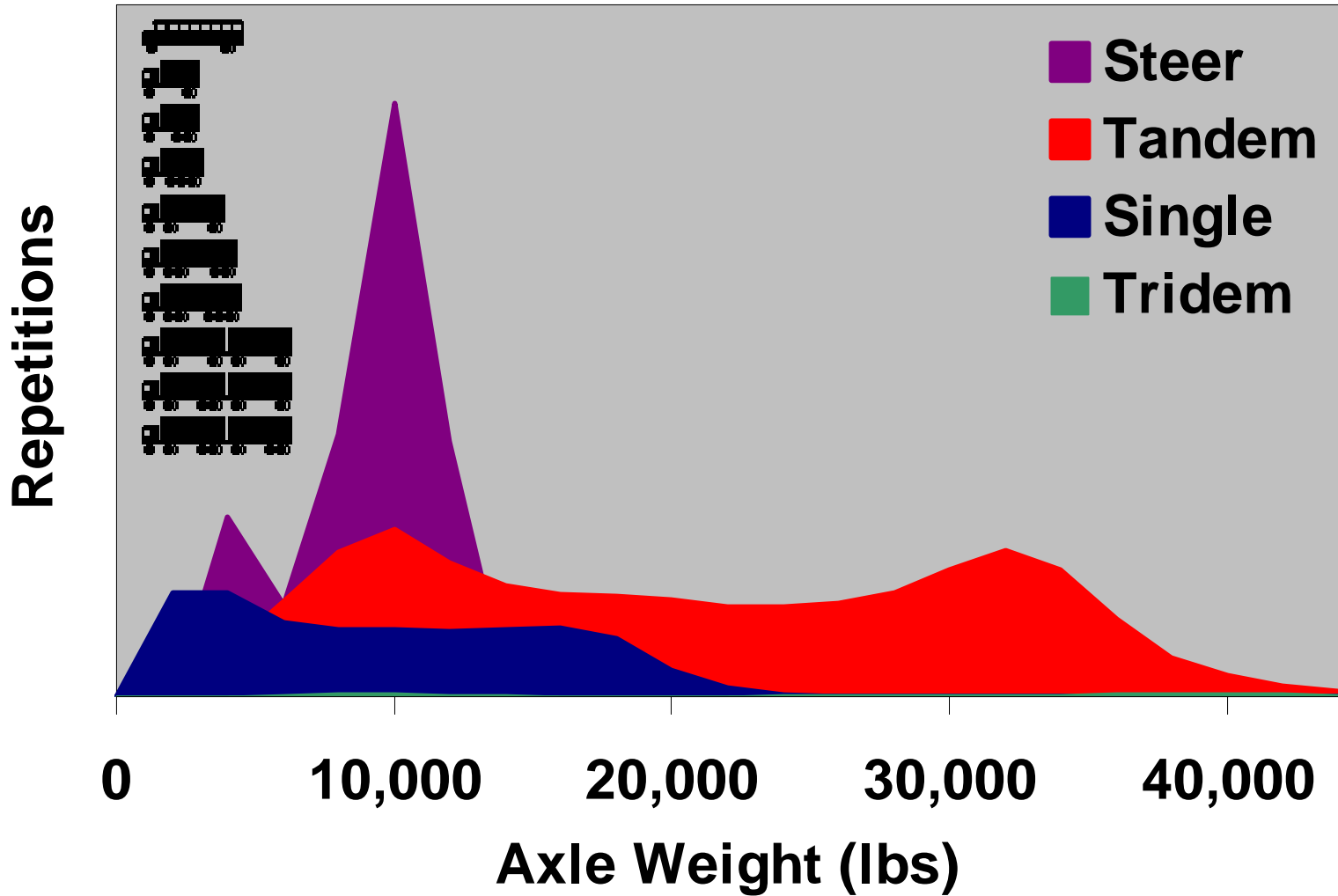


Simplified Load Spectrum Input

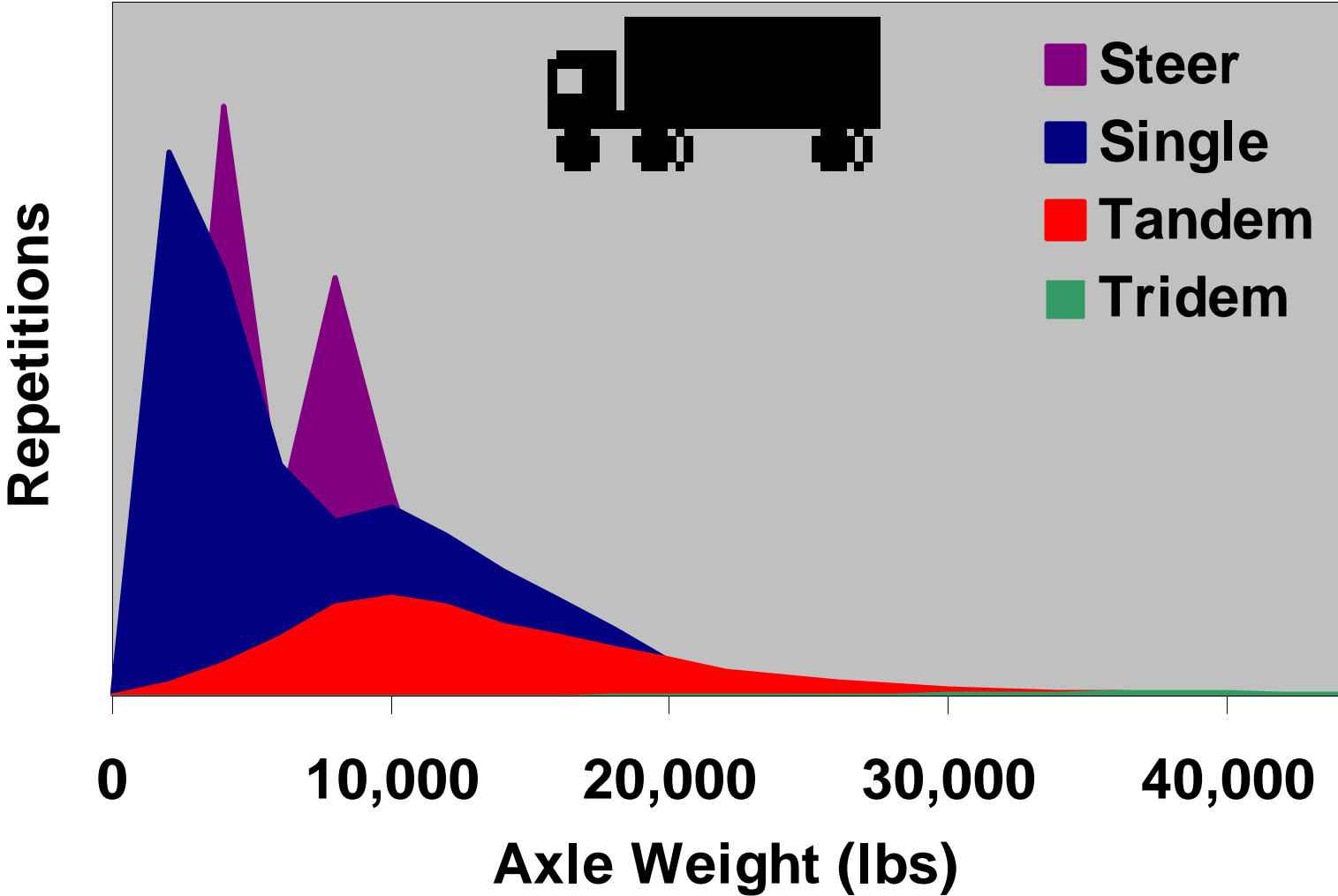
- Analysis of WIM data
- Mn/DOT and FHWA vehicle types
- Axle distributions by truck type
- Assumptions about truck distributions
- Route types



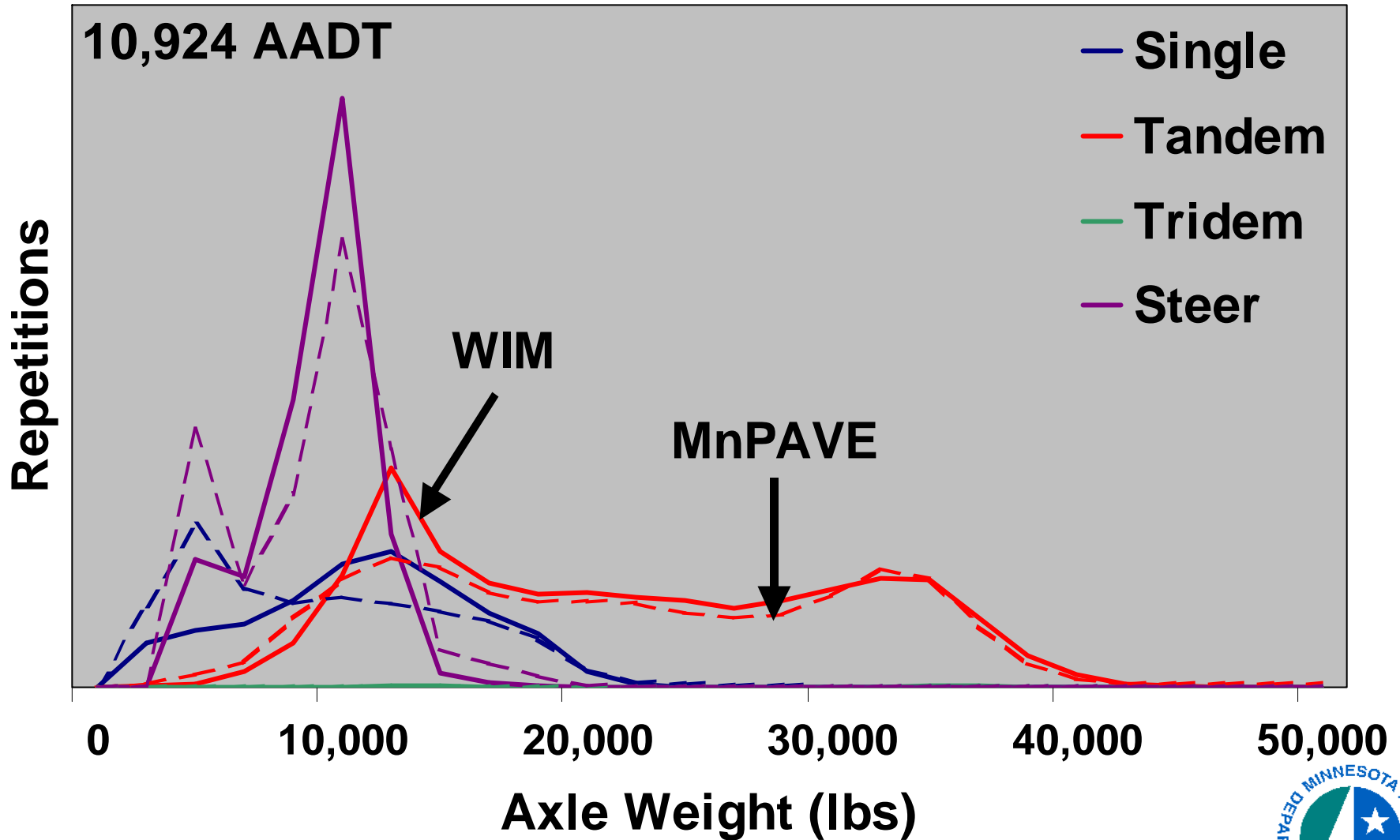
MnROAD 2001 WIM Data

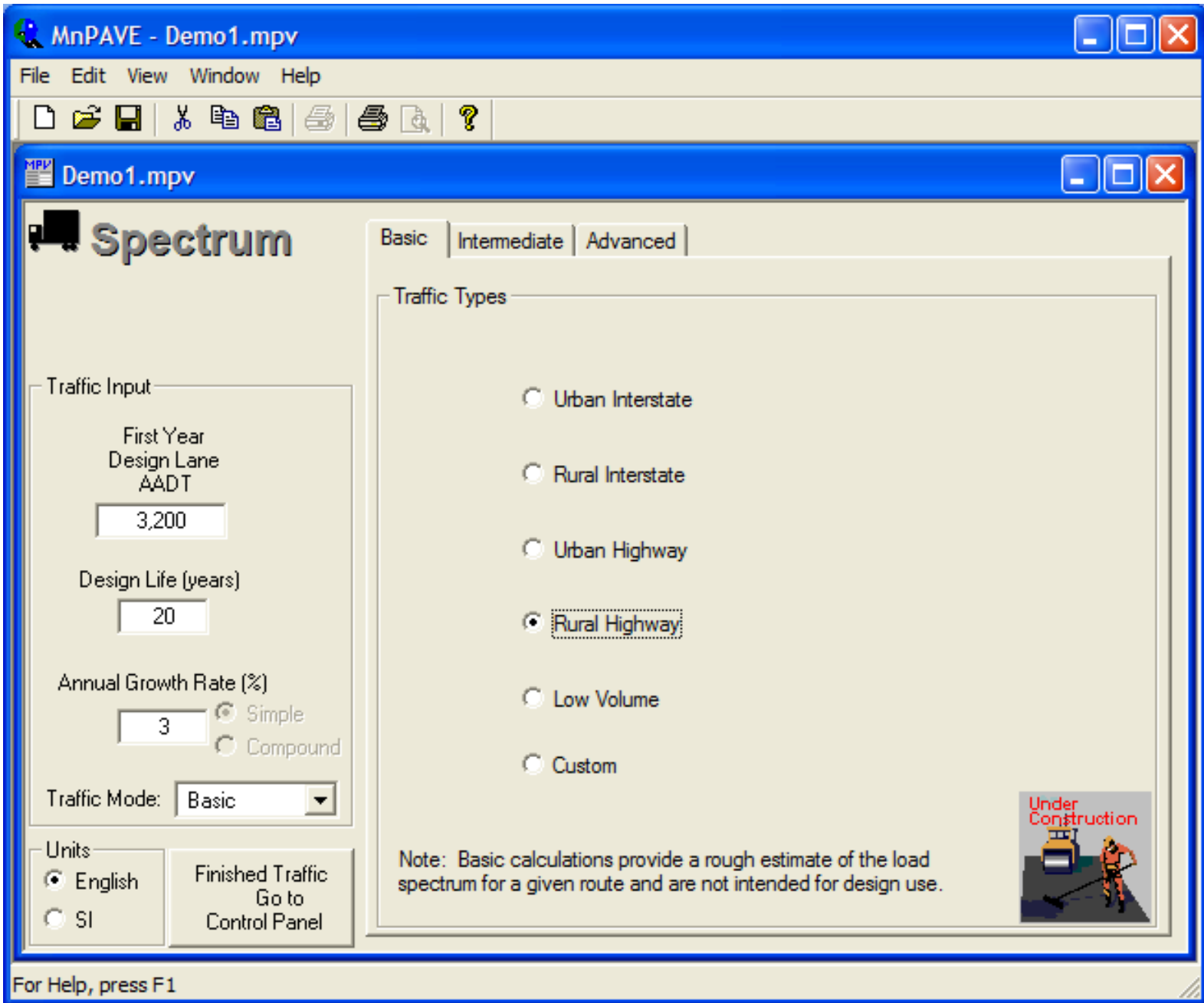


Vehicle Type 8



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





MnPAVE - Demo1.mpv

File Edit View Window Help

MnPAVE Demo1.mpv

Spectrum

Basic Intermediate Advanced

Standard VehicleTypes Custom Traffic

Mn/DOT FHWA

Traffic Input

First Year Design Lane AADT

Design Life (years)

Annual Growth Rate (%)

Simple Compound

Traffic Mode:

Units

English SI

Finished Traffic
Go to Control Panel

Type No.	Description	Percent	Icon	Notes
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.

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)	<input checked="" type="checkbox"/> Dual	<input checked="" type="checkbox"/> Tandem	<input checked="" type="checkbox"/> Tridem	<input checked="" type="checkbox"/> Steer	<input type="checkbox"/> Single	<input type="checkbox"/> Tandem	<input type="checkbox"/> 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			

Clear All Rural Highway Calculated ESALs = 2,103,608 Show LEF

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

For Help, press F1



Output

MnPAVE - Demo1.mpv

File Edit View Window Help

MPV Demo1.mpv

Output Life Damage

Traffic Type: Load Spectrum Total Repetitions: 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	
MnPAVE Fatigue	9.2	0.2	0.8	14.7	75.1	
MnPAVE Rutting	17.2	0.2	0	25.9	56.6	


Export

Design Summary Damage Details

Export to File

For Help, press F1

NUM





Questions

www.mrr.dot.state.mn.us

