Proposed System for Co-ordinating Spring Load Restrictions in Ontario

Max Perchanok, Research Coordinator, Ontario Ministry of Transportation
Heather McClintock, Maintenance Engineer, Ontario Ministry of Transportation*
Steve Birmingham, Maintenance Officer, Ontario Ministry of Transportation
Juan Pernia, Professor, Lakehead University
Robert Timoon, Research Associate, Lakehead University

Paper prepared for presentation
at the Better, Faster, Safer Road Maintenance Session
of the 2013 Conference of the
Transportation Association of Canada
Winnipeg, Manitoba

*Presenting author

Proposed System for Co-ordinating Spring Load Restrictions in Ontario

Abstract

Load restrictions are imposed by many road agencies to prevent excessive pavement damage on low volume roads during the spring thaw period. A variety of methods and criteria are used to establish restriction dates, creating uncertainty for commercial road users. New models were recently developed that use air temperature observations and forecasts from a provincial RWIS network to predict subsurface thaw depths and associated load restriction dates for surface treated highways. This provides scientifically-based projections to assist decision makers in determining load restriction dates to observed weather conditions in any year. Future developments will extend the predictions to any location in the province.

1. Introduction and Objectives

Roads and highways in northern climates are affected by seasonal growth and melting of ice beneath the surface, especially on roads with a non-engineered base beneath the driving surface. Ice growth can be advantageous by increasing the bearing strength of road materials, or disruptive where moisture accumulates locally in frost heaves or boils. Melting of ice can lead to weakening of road materials where melt near the surface is more rapid than at depth, and excess moisture is trapped above a non-permeable subsurface layer, leading to rutting and pavement cracking.

The effects of freezing and thawing of low volume roads in Ontario is mitigated through temporary Winter Weight Premiums (WWP) during the frozen season and Half Load Restrictions or Spring Load Restrictions (SLR) during the thaw season on designated road sections (Ontario, 2013). They are intended to provide a balance between the access needed by the trucking and resource industry and the added road repair and maintenance costs borne by the Ministry of Transportation or local municipalities.

WWP and SLR on Provincial Highways are governed by fixed schedules based on long-term Regional experience of freezing and thawing conditions, with adjustments based on periodic observations of roadside drainage or pavement deterioration. Regulations require that the trucking industry is given five days notice of changes to road postings, and this requires significant experience and some risk in decision-making.

A project was initiated in 2005 with the intention to develop an engineering-based advisory system that staff can refer to in setting future dates for WWP and SLR, adjusting them to freezing and thawing conditions each winter in each area. The Provincial Road Weather Information System (RWIS), which provides web access to 140 weather and pavement surface monitoring sites across the province, was viewed as a suitable host for the system.

This paper describes the conceptual approach, development and implementation of the system.

2. Approach

The overall approach entailed a progressive move from observation to prediction, and finally to forecasting of frost conditions and posting dates. This was accomplished through the five major tasks listed below:

1. Conduct a literature review to identify promising methods used elsewhere to observe and forecast ground freezing and thawing conditions and their relation to critical changes in strength of surface-treated roads.
2. Develop an observational network on atmospheric and subsurface conditions at representative, frost-susceptible sites.
3. Develop an empirical prediction of frost and thaw depth with calibrations and seasonal switches specific to each site, and criteria relating the depths to the need for WWP or SLR.
4. Improve the model with regional calibrations and automated seasonal switches, with experimentally confirmed freeze-thaw depth criteria.
5. Develop generic, physically-based calibrations using a thermal-numerical layer model for representative geotechnical profiles, allowing extrapolation to any site in the province.

3. Results

3.1 Literature Review

SLRs have been implemented by many jurisdictions in Canada and the United States to reduce the amount of pavement distress during spring thaw weakened periods. Previous research has shown that they should be implemented when the thawing front passes through the base layer as aggregate base stiffness is dramatically reduced (Van Deusen, 1998), and removed when the subsurface has completely thawed (Anderson and Ladanyi, 2004) The freeze-thaw conditions are associated with reduction and subsequent recovery of the composite modulus as measured with a Portable Falling Weight Deflectometer (PWFD) (Steinert et al, 2005)].

Highway agencies have implemented frost depth monitoring in association with RWIS (Baiz et al, 2008) however, this provides only current information which provides limited assistance in providing the advance warning that is required in Ontario.

Several approaches have recently been taken to prediction of thaw depths and restriction dates. A project sponsored by FHWA through CLARUS utilized the Enhanced

Integrated Climate Model (EICM) to simulate pavement, sub-base, and sub-grade conditions based on observed and forecast weather parameters. The tool provides graphic profiles of subsurface conditions down to 48 inches and forecasts out to about three weeks. The EICM was developed as part of Clarus Use Case #2 project in North Dakota, South Dakota, and Montana (FHWA-JPO-11-117). Other systems use physical measurement of pavement strength, or semi-empirical degree-day models to estimate subsurface temperature profiles, frost and thaw depths, or the dates when critical conditions are expected (Tighe, Mills and Baiz, 2007; Chapin, Pernia, Kjartanson and Perchanok, 2010). The models can be coupled with atmospheric forecasts to provide advance warning of the estimated dates when winter weight premiums or spring load restrictions should be placed and lifted.

3.2 Observational network

Permanent instrumentation was installed at nine sites at locations identified as having susceptibility to spring thaw settlement or rutting (pink markers in Figure 1). The instrumentation included atmospheric and sub-surface sensors. Atmospheric sensors monitor air temperature and humidity, wind speed and direction, and in some cases precipitation. Subsurface sensors were installed near the centreline of the road to monitor temperature at up to 10 depths as low as 255 cm below the surface earth. Moisture content and earth pressure are also measured. The sensors are polled at regular intervals and relayed automatically to the Ministry's RWIS, where they can be viewed on the web in real time and are archived for future analysis (Figure 2).

The example web page in Figure 2 illustrates twice-daily observations of subsurface temperature and moisture at Highway 66 near New Liskeard, during a period of thaw penetration in late March. Key aspects of the subsurface temperature profile include a rapid warming progression indicated by successive appearance of yellow, red and blue colours surrounding a colder core of grey, with thaw progressing rapidly from the top down and more slowly from the bottom up. On March 19 most of the soil column is frozen and by March 31 it is nearing the thawed state. Soil moisture values are highest near the top of the frozen zone (note scale on left side should read mm not cm).

An incidental feature shown in Figure 2 is the obviously erroneous temperature readings at 5 cm and 195 cm depth. These may result from moisture penetration to the thermistors or damage to the signal cables from the sensors to the roadside data logger, and illustrate the importance of data quality checks and redundancy in the field instrumentation system in the very hostile field environment beneath a frozen road.

3.3 Empirical Prediction

In an initial effort to provide a forecast of frost and thaw depths, the University of Waterloo (Tighe et al, 2007) developed a degree-day index model to predict the depth of freezing early in winter and the depth of thawing from the top and bottom as the thawing season progresses. The index approach is similar to one developed in Minnesota (Ovik et al, 2000), with the difference that the Ontario model predicts frost and thaw depth rather than the load restriction start date. Empirical coefficients account for differences in geotechnical characteristics at each instrumented site. It has the advantage of requiring only the time series of air temperatures as input, and can project frost and thaw depths as far into the future as the daily air temperature forecast (Figure 3). Different coefficients are used for the freezing and thawing seasons, and a heuristic approach was initially used to identify the time when the coefficients should be switched. This did not impact the model implementation since weeks elapse between the end of the frost-progression season and warming of the road base materials through the freezing point however, it requires interpretation by a dedicated analyst which may not be available in the proposed RWIS implementation.

3.4 Regionally Calibrated Model

In a later model version developed at Lakehead University, the switch from freezing to thawing prediction was automated using a reference temperature, and the Minnesota approach was adopted to provide a direct recommendation of the dates when WWP and SLR should be initiated and removed (Figure 4) (Chapin et al, 2010).

Comparison of frost and thaw depth progression at 7 sites with a variety of geotechnical profiles in Northeastern and Northwestern Ontario indicated that one calibration from each Region was representative of most sites in those areas (Figure 5), and the two Regional models have been adopted as an interim measure (Chapin et al, 2012).

A thaw depth of 300 mm was proposed as a working criterion for beginning load restrictions and full depth thaw was proposed to remove restrictions, based on recommendations found in the literature. An ongoing program of field measurement of pavement deflection in comparison with thaw depth during the thaw period has thus far confirmed those values, as illustrated in Figure 6.

3.5 Future Plans

An approach was developed to improve the current system by using a thermal-numerical model to simulate frost and thaw progression for a wider variety of characteristic geotechnical profiles and moisture conditions found in Ontario, and to use the model results to calibrate the degree-day models (Chapin et al, 2009b). This will allow the road manager to select from a variety of model calibrations the one which most closely corresponds to the site in question, and then to select air temperature input data from the nearest RWIS or other weather observing station, to provide a load restriction recommendation for any road at any location.

The new tools have been added to MTO`s RWIS web page and are available to Regional staff who make decisions about WWP and SLR. A training program is planned for the coming winter to help staff understand and gain confidence in the new tools, and to remain closely involved in the next phase of modelling.

4. Conclusions

Tools have been added to the Ministry of Transportation`s RWIS web site that provide observations and forecasts of frost and thaw depths, and estimated critical dates for the initiation and ending of Winter Weight Premiums and Spring Load Restrictions.

With a training program planned for the fall of 2013, the system will provide a sound engineering basis for adjustment of the dates based on varying seasonal weather conditions and will help balance the interests of the Ministry in minimizing thaw-related repair costs while providing improved access to the trucking industry.

5. References

Andersland, O., Ladanyi, B. (2004), Frozen Ground Engineering 2nd Ed., The American Society of Civil Engineers and John Wiley & Sons, Inc.

Baiz, S., Tighe, S.L., Haas, C.T., Mills, B., Perchanok, M. (2008), *Development and Calibration of Frost and Thaw Depth Predictors for Use in Variable Load Restrictions Decision-Making on Flexible Low-Volume Roads*, Transportation Research Record, Journal of the Transportation Research Board No. 2053, pp 1-20

Chapin, J, J Pernia, B. Kjartanson, 2009, An Approach to Applying Spring Thaw Load Restrictions for Low Volume Roads Based on Thermal Numerical Modelling, American Society for Civil Engineering, 14th ASCE Cold Regions Conference.

Chapin, J, J. Pernia, B. Kjartanson and M. Perchanok, 2010, An Assessment of Two Approaches for Applying Spring Load Restrictions on Low Volume Roads, Canadian Society for Civil Engineering, Annual Conference.

Chapin, J., Pernia, J.C., and Kjartanson, B.,2012 “Optimization of Seasonal Frost/Thaw Depth and Pavement Strength on Low Volume Highways in Ontario”, Research Report to the Ministry of Transportation of Ontario, Department of Civil Engineering, Lakehead University, 2012.

FHWA-JPO-11-117; Clarus Multi-State Regional Demonstrations; Use Case #2, Seasonal Load Restriction Tool.

Steinert, B.C., Humphrey, D.N., Kestler, M.A. (2005), *Portable Falling Weight Deflectometer Study*, New England Transportation Consortium, Report No. NETCR52

Tighe, S., B. Mills and S. Baiz, 2007. An approach to applying spring thaw load restrictions to low volume roads. Transportation Association of Canada Annual Meeting. (University of Waterloo)

Van Deusen, D. (1998), *Improved Spring Load Restriction Guidelines Using Mechanistic Analysis*, Cold Regions Impact of Civil Works, Ninth International Conference on Cold Regions Engineering, pp 188-199

6. Acknowledgements

The authors thank MTO staff in Northeast and Northwest Regions, particularly Doug Plaunt, Brian Scott, Doug Flegel and Don Petryna for assistance with field work and Dale Willis, Jason Wright, Fiona Leung, Dino Leombruni with operational and technical matters.

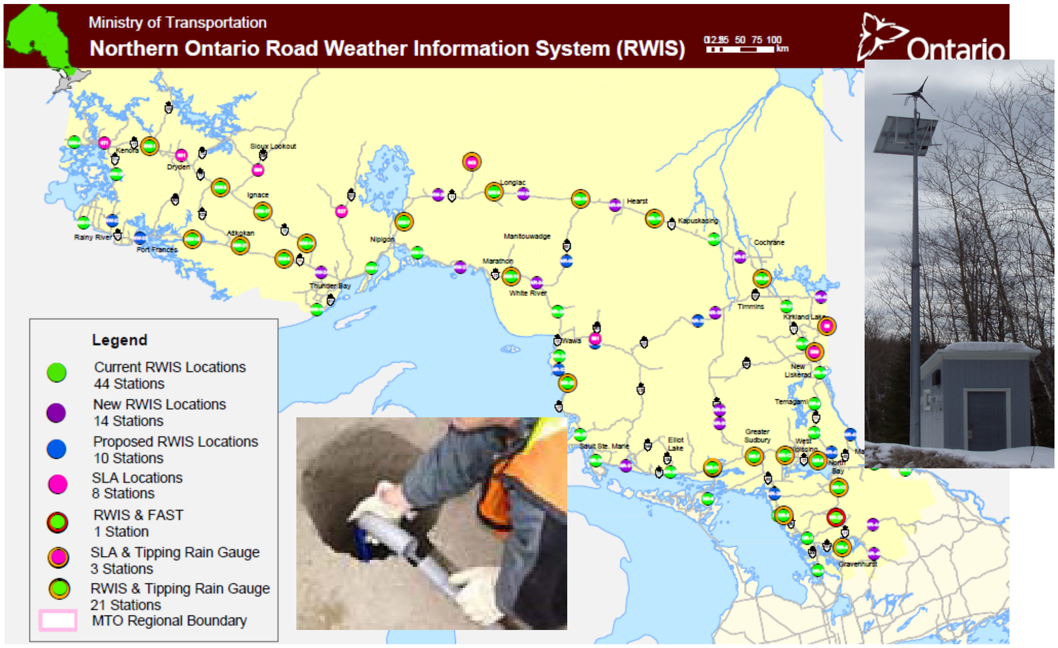
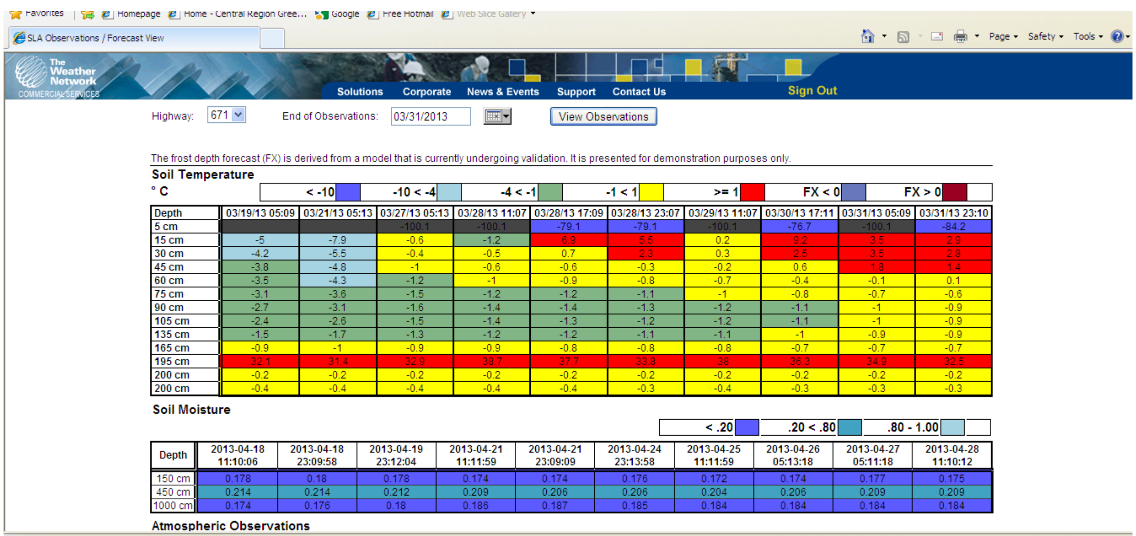


Figure 1. RWIS Network in Northern Ontario



Soil Temperature

° C: < -10 | -10 < -4 | -4 < -1 | -1 < 1 | >= 1 | FX < 0 | FX > 0

Depth	03/19/13 05:09	03/21/13 05:13	03/27/13 05:13	03/28/13 11:07	03/28/13 17:09	03/28/13 23:07	03/29/13 11:07	03/30/13 17:11	03/31/13 05:09	03/31/13 23:10
5 cm			-100.1	-100.1	-79.1	-79.1	-100.1	-76.7	-100.1	-84.2
15 cm	-5	-7.9	-0.6	-1.2	6.9	5.5	0.2	9.2	3.5	2.9
30 cm	-4.2	-5.5	-0.4	-0.5	0.7	2.3	0.3	2.5	3.5	2.8
45 cm	-3.8	-4.8	-1	-0.6	-0.6	-0.3	-0.2	0.6	1.8	1.4
60 cm	-3.5	-4.3	-1.2	-1	-0.9	-0.8	-0.7	-0.4	-0.1	0.1
75 cm	-3.1	-3.6	-1.5	-1.2	-1.2	-1.1	-1	-0.8	-0.7	-0.6
90 cm	-2.7	-3.1	-1.6	-1.4	-1.4	-1.3	-1.2	-1.1	-1	-0.9
105 cm	-2.4	-2.6	-1.5	-1.4	-1.3	-1.2	-1.2	-1.1	-1	-0.9
135 cm	-1.5	-1.7	-1.3	-1.2	-1.2	-1.1	-1.1	-1	-0.9	-0.9
165 cm	-0.9	-1	-0.9	-0.9	-0.8	-0.8	-0.8	-0.7	-0.7	-0.7
195 cm	32.1	31.4	32.9	38.7	37.7	33.8	38	36.3	34.9	32.5
200 cm	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
200 cm	-0.4	-0.4	-0.4	-0.4	-0.4	-0.3	-0.4	-0.3	-0.3	-0.3

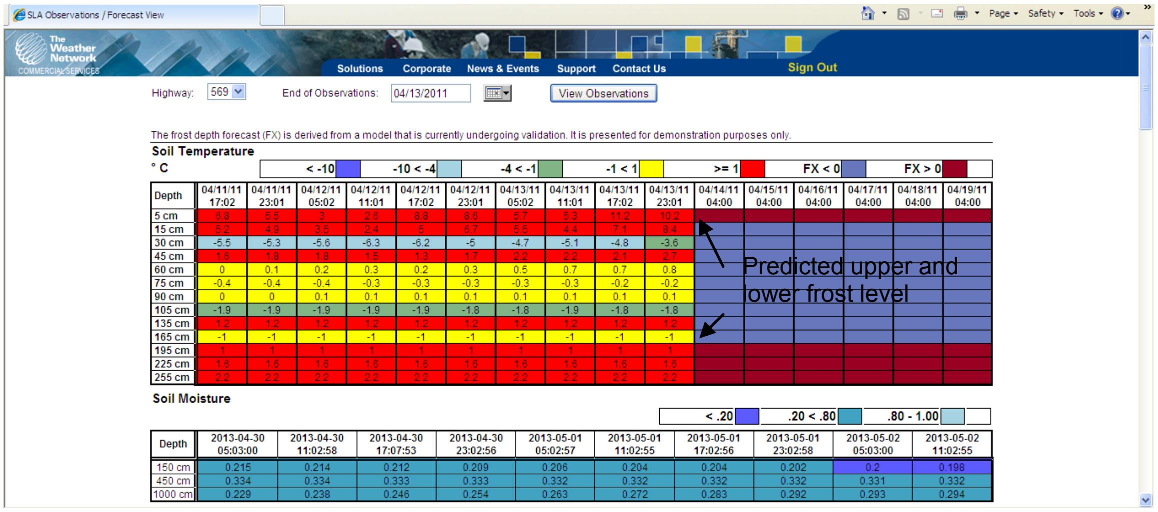
Soil Moisture

< .20 | .20 < .80 | .80 - 1.00

Depth	2013-04-18 11:10:06	2013-04-18 23:09:58	2013-04-19 23:12:04	2013-04-21 11:11:59	2013-04-21 23:09:09	2013-04-24 23:13:58	2013-04-25 11:11:59	2013-04-26 05:13:18	2013-04-27 05:11:18	2013-04-28 11:10:12
150 cm	0.178	0.18	0.178	0.174	0.174	0.176	0.172	0.174	0.177	0.175
450 cm	0.214	0.214	0.212	0.209	0.206	0.206	0.204	0.206	0.209	0.209
1000 cm	0.174	0.176	0.18	0.186	0.187	0.185	0.184	0.184	0.184	0.184

Atmospheric Observations

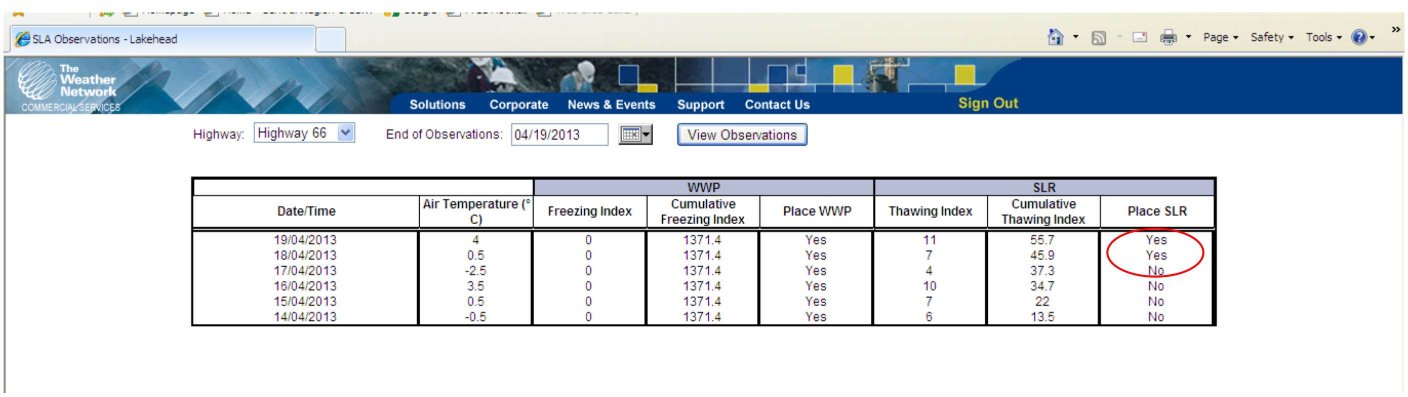
Figure 2. Seasonal Load Advisory subsurface observations web page



Depth	04/11/11 17:02	04/11/11 23:01	04/12/11 05:02	04/12/11 11:01	04/12/11 17:02	04/12/11 23:01	04/13/11 05:02	04/13/11 11:01	04/13/11 17:02	04/13/11 23:01	04/14/11 04:00	04/15/11 04:00	04/16/11 04:00	04/17/11 04:00	04/18/11 04:00	04/19/11 04:00
5 cm	6.8	5.5	3	2.6	8.8	8.6	5.7	5.3	11.2	10.2						
15 cm	5.2	4.9	3.5	2.4	5	6.7	5.5	4.4	7.1	8.4						
30 cm	-5.5	-5.3	-5.6	-6.3	-6.2	-5	-4.7	-5.1	-4.8	-3.6						
45 cm	1.6	1.8	1.8	1.5	1.3	1.7	2.2	2.2	2.1	2.7						
60 cm	0	0.1	0.2	0.3	0.2	0.3	0.5	0.7	0.7	0.8						
75 cm	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2						
90 cm	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1						
105 cm	-1.9	-1.9	-1.9	-1.9	-1.9	-1.8	-1.8	-1.9	-1.8	-1.8						
135 cm	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2						
165 cm	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1						
195 cm	1	1	1	1	1	1	1	1	1	1						
225 cm	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6						
255 cm	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2						

Depth	2013-04-30 05:03:00	2013-04-30 11:02:58	2013-04-30 17:07:53	2013-04-30 23:02:56	2013-05-01 05:02:57	2013-05-01 11:02:55	2013-05-01 17:02:56	2013-05-01 23:02:58	2013-05-02 05:03:00	2013-05-02 11:02:55
150 cm	0.215	0.214	0.212	0.209	0.206	0.204	0.204	0.202	0.2	0.198
450 cm	0.334	0.334	0.333	0.333	0.332	0.332	0.332	0.332	0.331	0.332
1000 cm	0.229	0.238	0.246	0.254	0.263	0.272	0.283	0.292	0.293	0.294

Figure 3. Forecast of Frost and Thaw Depth



Date/Time	Air Temperature (°C)	WWP			SLR		
		Freezing Index	Cumulative Freezing Index	Place WWP	Thawing Index	Cumulative Thawing Index	Place SLR
19/04/2013	4	0	1371.4	Yes	11	55.7	Yes
18/04/2013	0.5	0	1371.4	Yes	7	45.9	Yes
17/04/2013	-2.5	0	1371.4	Yes	4	37.3	No
16/04/2013	3.5	0	1371.4	Yes	10	34.7	No
15/04/2013	0.5	0	1371.4	Yes	7	22	No
14/04/2013	-0.5	0	1371.4	Yes	6	13.5	No

Figure 4. Load Restriction Recommendation from Lakehead Model

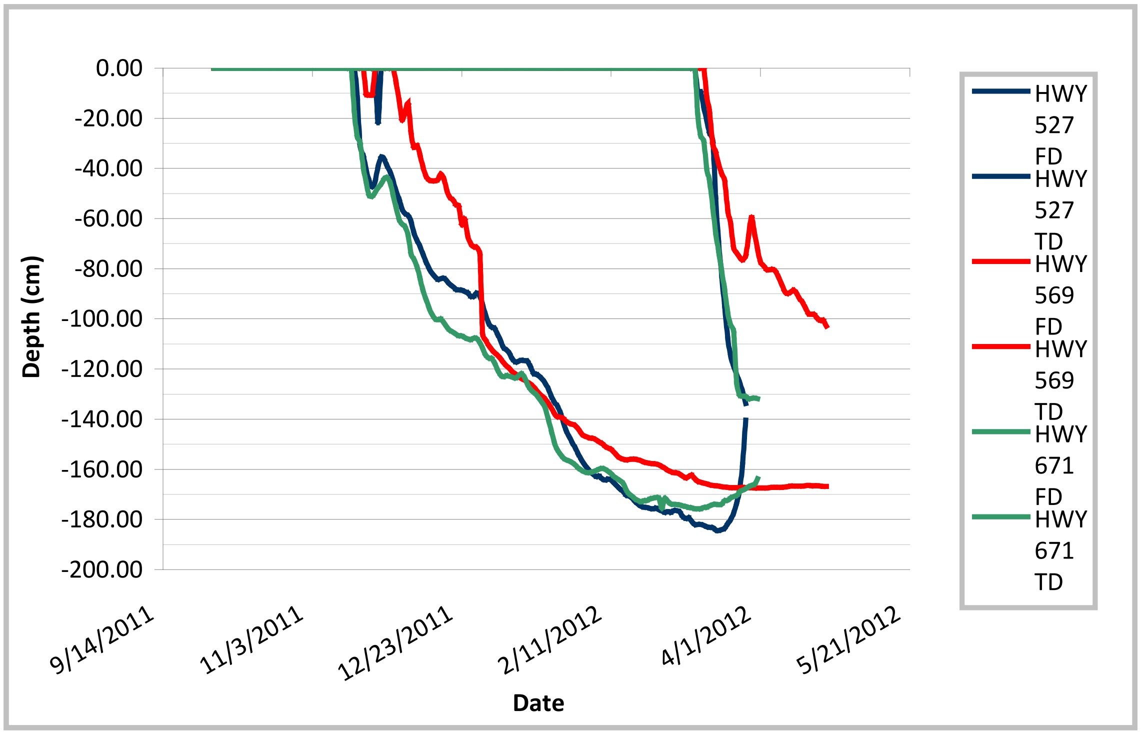


Figure 5. Frost and Thaw Depth Comparison at Test Sites

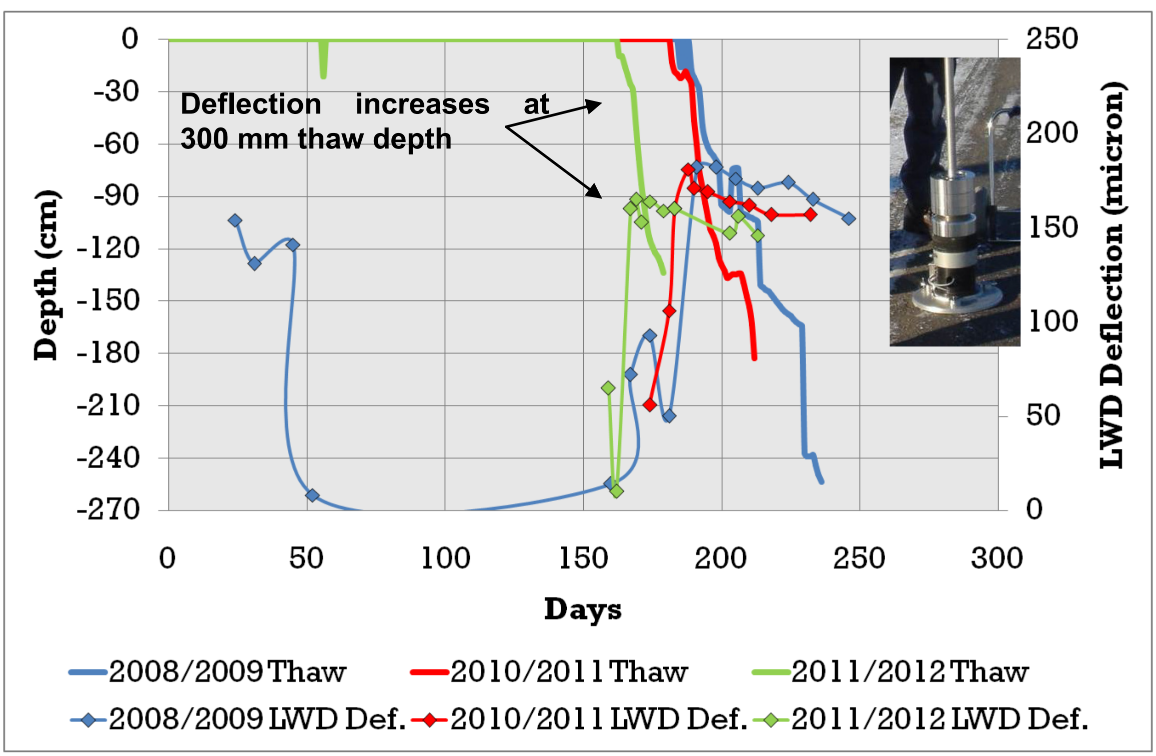


Figure 6. Observed Relation of Pavement Strength to Thaw Depth, Highway 527