Spring Thaw Predictor & Development of Real Time Spring Load Restrictions

Final Report

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16. Abstract

This report summarizes the results of a study to develop a correlation between weather forecasts and the spring thaw in order to reduce the duration of load limits on New Hampshire roadways. The study used a falling weight deflectometer at 10 sites in central New Hampshire to determine the changes in road subgrade strength. Weather condition and frost depth data was collected at the same time.

The goal of the study was to calibrate the Enhanced Integrated Climate Model (EICM) within the Mechanistic Empirical Pavement Design Guide (MEPDG) using correlations developed between the subsurface conditions and the strength testing.

The project did not provide sufficient data to provide a definite conclusion as to when load restrictions should be lifted during the spring thaw. Some key observations: subsurface thawing can progress rapidly; subsurface strength may take up to five (5) weeks to recover, especially in wetter subgrade soils; subgrade soils were weakest after the date when frost was out of the soil; saturated soils lost strength during the spring thaw.

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DISCLAIMER

Spring Thaw Predictor & Development of Real Time Spring Load Restrictions

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Executive Summary

In an effort to clarify its spring load restriction policy, the New Hampshire Department of Transportation (NHDOT) conducted a research project to develop a correlation between roadway strength, subsurface conditions, and climatic conditions for typical New Hampshire roadways. These correlations and the current weather forecast will be used by a subsurface condition prediction tool, also being developed by this project, to assist NHDOT personnel in determining when to apply and lift weight restriction postings.

Subsurface temperature and moisture sensors, frost tubes, weather stations, and water table monitoring wells have been installed at six locations in District 2 and one in District 3. Pavement deflection measurements were taken at these locations throughout the thawing periods of 2008 and 2009.

The new Mechanistic Empirical Pavement Design Guide (MEPDG), adopted by American Association of State Highway and Transportation Officials (AASHTO) in 2008 as the interim pavement design guide, incorporates the Enhanced Integrated Climatic Model (EICM) to estimate subsurface conditions. The subsurface, climatic, and deflection data collected by this project would be used to calibrate the EICM to New Hampshire conditions. The NHDOT has partnered with the US Department of Agriculture (USDA) Forest Service for modification of the EICM into a real-time subsurface condition prediction tool based on the current 10-day forecast. The roadway strength would be determined by the correlations developed between the subsurface conditions and the strength testing.

This report describes the first three years of the project including test site selection, instrumentation, and testing. The strength testing was performed during the second season because of equipment availability. NHDOT contracted work with the USDA Forest Service; whereby, the Forest Service contracted a programmer to develop the EICM-based subsurface prediction tool.

This report summarizes the data collection during the project. Data includes frost depth, subsurface temperature, and water table elevations, atmospheric weather conditions and strength testing data during the thawing seasons. Subsurface moisture data was partially recorded for two of the thawing seasons.

The strength testing was performed with a falling weight deflectometer (FWD). The spring thaw testing indicated that the roadways generally lose strength quickly down to the point where the subsurface is fully thawed. The roadway then recovers strength back to a baseline condition but not as strong as the fully frozen condition.

As an added feature, the weather stations at the Wentworth, Rumney, and Bristol sheds and the District 2 office were added to the NHDOT’s Road Weather Information System (RWIS) in cooperation with Plymouth State University, New Hampshire Department of Information Technology (DoIT), and the NHDOT Transportation Management Center (TMC) to provide real-time methodology that can be used by the NHDOT for roadway strength analysis and the TMC for travel conditions.

Background

Like many northern states, New Hampshire posts load restrictions on its secondary roadways during the spring thawing period. This is done to prevent damage to the roadway when the subsurface is saturated and unable to bear heavy loads. As the thaw progresses and the subsurface dries out, the roadway recovers its strength. Weight restrictions are lifted when it is judged that sufficient strength has been recovered.

At the same time that the NHDOT is trying to preserve its roads, it must also try to minimize the impact the postings cause to the local economies that depend on the roadways. Logging and construction are two industries in particular that suffer because of the load restrictions. Equipment cannot be moved to or from work sites and logs and lumber cannot be transported to or from mills during this time. In rural and especially northern New Hampshire, lumber, wood chip, and pulp operations can be a significant part of the local economy. The losses to an individual logging operation during weight restrictions can be in the neighborhood of $1,000 to $2,000 per day. Wood chip fired power plants typically stockpile as many loads of wood chips as they can handle during the winter to alleviate the impact of the postings on deliveries in the spring.

This tension between the need to preserve the roadway system and the need to keep the local economy working means that the restrictions should be posted only when they are needed. To this end, the NHDOT needs to develop a sound methodology for determining when to post and when to lift the load restrictions. Currently, the methodology is based upon the judgment and experience of the personnel in each Maintenance District. They use surface evidence of thawing and current weather conditions. The subsurface conditions and its effect upon the strength of the roadway is an unknown factor. More information about the subsurface conditions and the roadway strength would allow the NHDOT to post weight restrictions in a manner that protects the roadway yet minimizes the effect on the local economies.

The USDA Forest Service oversees many roads in northern states and struggles with the same balancing act of roadway protection verses impact to the local economy. In early 2006, Maureen Kestler, a civil engineer for the Forest Service, and Robert Eaton, a civil engineer for the NHDOT, both submitted proposals for research dealing with implementing spring load restrictions to the NHDOT Research Advisory Council (RAC). They were directed to combine their proposals into one project for presentation to the RAC for consideration.

Research Project

In April of 2006, the NHDOT Research Advisory Council approved this research project, entitled “Spring Thaw Predictor and Development of Real Time Spring Load Restrictions”, with the objective of developing a roadway strength prediction tool to supplement the roadway maintenance personnel determination of when to post and lift weight restrictions. The end product will be a software program that uses the known effects of climatic and environmental conditions on roadway consistent with the 10-day weather forecast to predict the roadway strength during that period. The maintenance personnel can access the results for predictions and determine if posting weight restrictions is necessary.

The center of the prediction program is the Enhanced Integrated Climatic Model (EICM). The EICM is a subsurface condition model that is embedded in the new AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG). The EICM takes into account material properties and environmental conditions to model subsurface conditions. These subsurface conditions directly affect the load-bearing ability of the roadway. Due to the variation of materials, climate, and environment throughout the nation, it is good practice to calibrate the EICM locally and obtain modeling that accurately reflects the local conditions. In the case of this project, the data is being gathered to calibrate to New Hampshire specific materials and conditions. The calibrated EICM will then be incorporated into a stand-alone program with the 10-day weather forecast to predict the roadway strength.

The original work plan for this project was to collect the data necessary to calibrate the EICM during one thawing season and develop the thawing prediction program prior to the next thawing season. The second thawing season would be used to validate the predictions from the program against data being collected concurrently. The prediction tool would then be refined and completed. Due to delays in equipment procurement, incomplete climatic data, and no strength test data during the 2007 winter and thawing season, the initial data collection phase of the project was extended through the 2008 winter and thawing season. Work on the prediction program began in the summer of 2008 via a contract administered by the Forest Service to the modeler who has been developing the EICM. The Forest Service has worked with the modeler in the past and was able to contract with the modeler for the development of this prediction program. Data collected in the 2009 and 2010 winters and thawing seasons will be used to validate and refine the beta version of the prediction program.

This report describes the first three years of the project. During this period (2007-2009) sites were selected and instrumented, atmospheric and subsurface data was collected, and pavement deflection data was collected. The data collected in 2008 was analyzed and compared to predicted values from the EICM.

General Approach

Data was collected from nine sites in central New Hampshire. The sites were chosen to encompass various characteristics such as depth to water table, elevation, road orientation, surrounding vegetation, and subsurface soil type. It was expected that the sites would provide different rates of freeze/thaw, depths of frost penetration, subsurface temperature and moisture regimes, and varying load support conditions. These varying site characteristics and behaviors are helpful for a more optimum calibration of the EICM.

Atmospheric data and subsurface data were collected at all of the sites. Boring logs were taken during installation of the subsurface instrumentation. The nine locations consisted of seven roadway sites and two shed driveway sites. The site locations respective to each other are shown in Figure 1.

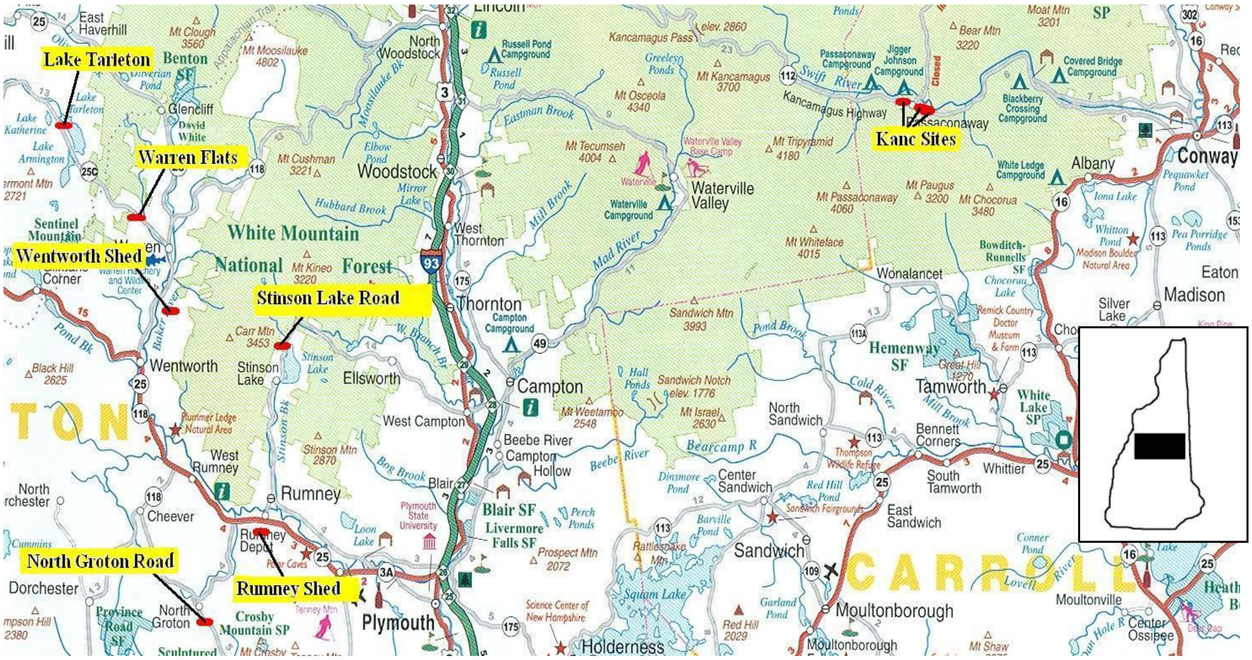


Figure 1: Location of Sites in Central NH (blacked out area is orientation of larger map)

The 6 sites to the west of Interstate 93 are known as the “District 2 sites” and the other three sites are all situated together on the Kancamagus Highway in Maintenance District 3 and are known as the “Kanc sites”.

Kancamagus Highway (Kanc) Sites

All Kanc sites are located on NH 112 (Kancamagus Highway) in a section that was rebuilt in 2005 (Figure 2). They are positioned in the eastbound lane about 24 miles east of Lincoln near the intersection of Bear Notch Road. In this area, the highway is level and adjacent lands heavily forested. The roadway has 4-foot paved shoulders and gravel edges that slope to drain water away from the pavement.

Kanc 1 is located just west of the intersection of Bear Notch Road and NH 112 in Albany, NH. This section of the highway was completely reconstructed in 2005 with 3.5" of pavement, 10" of crushed gravel, 10" of gravel, and 16" of sand. The material under the sand layer was characterized as sand and bedrock was encountered at a depth of 9 feet.

Kanc 2 is located about 1000' east of the intersection Bear Notch Road on NH 112. This section of the highway was reclaimed with cement added for stabilization in 2005. The reclaim was 8 inches in depth and cement was added at 4% by weight of dried aggregate.

Kanc 3 is immediately to the east of Kanc 2 on NH 112. The site was reclaimed in 2005 with no stabilizer added. The reclaim was 8" deep and 3.5" of pavement was placed over the reclaimed base. The material underneath the reclaimed base of both sections was characterized as sand with bedrock encountered at a depth of 11 feet.

Figure 2: Typical Kancamagus Highway Site (Kanc 2) looking east

District 2 Sites

The remaining six test sites are all in the western central part of the state within Highway Maintenance District 2. Two are located in the driveway of District 2 patrol sheds, two on rural state roadways, and two on a rural state highway a few miles apart.

The Lake Tarleton (LT) site is located in Piermont on an eastbound section of NH 25C that runs through a boggy area and is heavily forested on both sides (Figure 3). The road is elevated above the surrounding area approximately 3 to 4 feet and has a gravel shoulder approximately 1 to 2 feet wide. The ditch line is 3 to 4 feet from the edge of the pavement. A cross pipe carrying a small stream runs under the eastern end of the site. The pavement is cracked and about 9 inches thick. Below the pavement is a 6-inch layer of sand, followed by a 3-inch layer of coal tar and then 1-foot layer of silt and some organics classified as fill. Below this is silt and fine sand with some wood fragments encountered in the wash water during instrumentation installation at a depth of 5 feet. Exploration was stopped at a depth of 11 feet.

Figure 3: Lake Tarleton Site (in front of van) looking east

The Warren Flats (WF) site is located in Warren in the westbound lane of a section of NH 25C that runs through the middle of a field that gently slopes downwards from west to east (Figure 4). The road is level with and sometimes slightly below the field elevation, and the ditch line is immediately adjacent to the edge of the roadway. The roadway has a gravel shoulder approximately 1 to 2 feet wide. The field was actually a lakebed prior to a natural dam failure in the early 1800's. The pavement here is cracked and about 8 inches thick. The layer below the surface is characterized as coarse to fine sand to a depth of 2 feet. Below that there is loose silt, and fine sand characterized as glacial fluvial to the bottom of the exploration at a depth of 11 feet. This site has a highly variable water table (from 70 to 18 inches) and gets significant differential frost heaving.

Figure 4: Warren Flats site (between van and cone) looking west

The patrol shed sites were chosen because they are characterized by well-drained soils with deep bedrock. The depth of exploration for both shed sites was 10.5 feet. Bedrock was not encountered at either site. Both sites consist of fill over glacial till. The significant difference between the shed sites was pavement condition and the depth of fill.

The Rumney Shed (RS) site has approximately 6 inches of pavement above fine sandy to gravelly fill with traces of silt and debris to a depth of 4.5 feet. Below this is glacial till. The pavement at the Rumney Shed is in poor condition with many cracks, but not as extensively cracked as the Wentworth Shed (Figure 5).

The Wentworth Shed (WS) site has approximately 6 inches of pavement and then coarse sandy fill with traces of silt to a depth of 2.5 feet. Below this is glacial till. The pavement at the Wentworth Shed site is extremely heavily cracked, and due to this fact, it was eventually abandoned because of the errors it caused with the FWD (Figure 6).

Figure 5: Rumney Shed looking towards the road from the parking lot

Figure 6: Wentworth Shed looking away from the gas pumps

Figure 7: North Groton Road Site looking east

The North Groton Road (NGR) site is located in North Groton along a flat area at the top of a hill in the westbound lane (Figure 7). The roadway does not have a shoulder and there is a stone wall and a shallow ditch line one to three feet from the pavement edge. The roadway is a fairly recent four inch overlay on four inches of broken up pavement. The subsurface is noted as a two and one half foot layer of fill consisting of silt and fine sand over seven and one half feet of fine sand characterized as glacial till. Exploration was stopped at a depth of 11 feet.

The Stinson Lake Road (SLR) site is located in Rumney and was chosen because of its shallow ledge. The site is in the southbound lane (Figure 8). Boring logs show that the pavement at the site is 10 inches thick and the subsurface is layers of medium dense sand characterized as fill, glacial outwash, boulders, and glacial till. Refusal was encountered at 9.9 feet. The site is located at the base of a hillside about 100 yards from the lake. It is level with deciduous forest on either side of the site. The ditch line is immediately adjacent to the edge of the roadway and the roadway lacks a paved shoulder.

Figure 8: Stinson Lake Road Site looking south

Site Configuration and Instrumentation

The sites are all configured and instrumented in the same manner. Each site is 100 feet long and had 10 load strength test stations spaced 10 feet apart. Deflection measurements were taken at each of the stations. The stations were located in the right wheel path about 2.5 feet from the edge of the lane. Frost tubes, subsurface instrumentation, and water observation wells were located at the approximate midpoint of each site in line with the stations and separated from each other by 5 feet.

Figure 9 shows a typical site layout. There was also a weather station at each site to collect and record atmospheric weather data.

The frost tubes are tubes made out of clear plastic and filled with water and methyl blue dye. The frost location is determined visually by looking at color changes in the tube. As the water in the tube freezes the methyl blue turns clear, indicating frozen soil. As the ground thaws from the surface in the spring, the methyl blue turns blue again. The tubes are installed from the surface to a depth of 6 feet at all of the sites. The depths to the start and end of the frozen section of the frost tube are measured from the road surface and then recorded in a logbook. Figure 10 shows the typical access cap for a frost tube, and Figure 11 shows a partially frozen frost tube at the Wentworth Shed site.

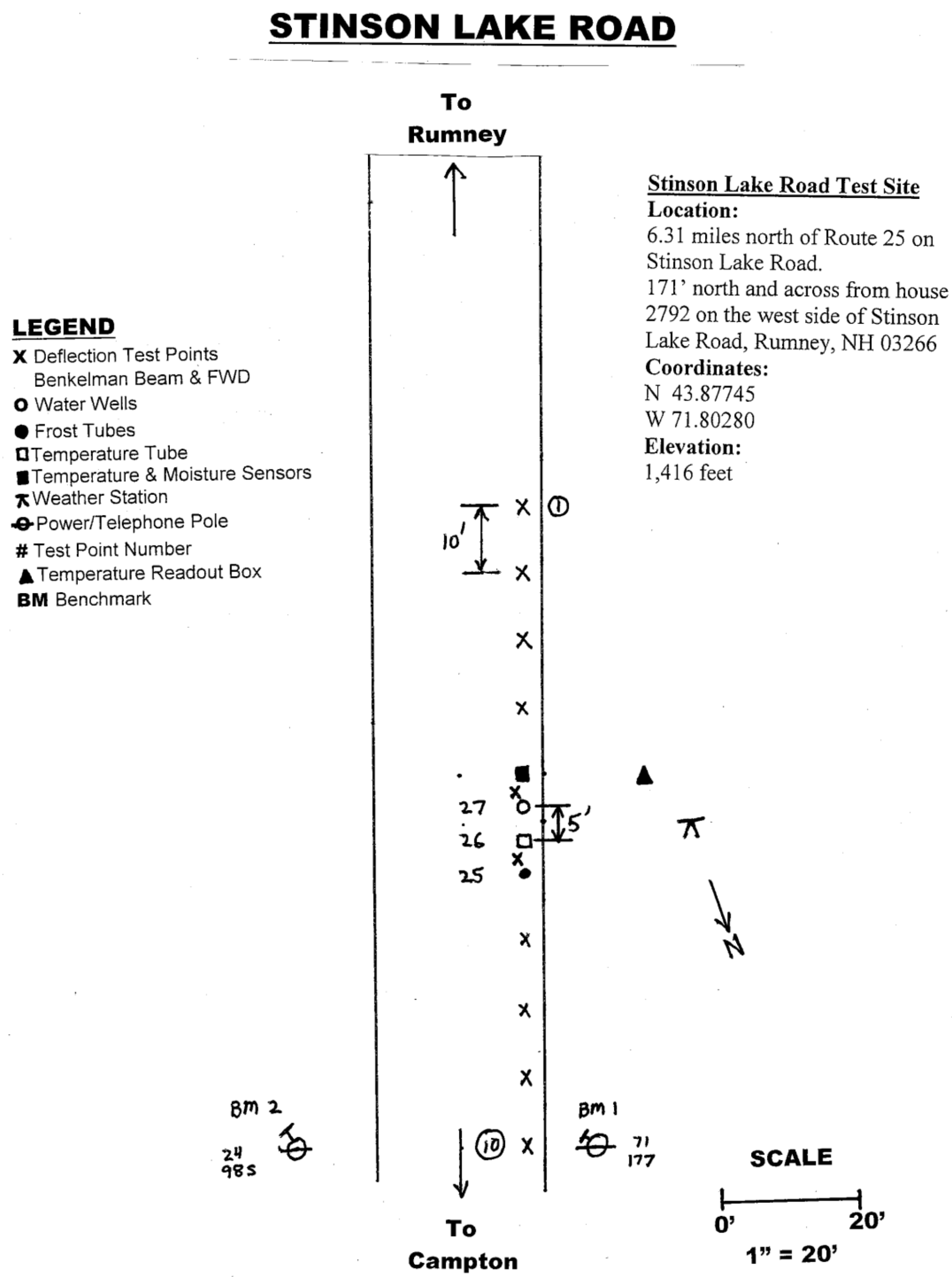


Figure 9: Typical site layout

Figure 10: Typical frost tube chamber at a site, the interior necks down to be just larger than the frost tube diameter to minimize the air space around the frost tube.

Figure 11: Frost tube with clearer colored frozen liquid in the top two-thirds and darker colored thawed liquid in the lower third.

The water observation wells were installed to a depth of 10 feet. The water table levels were measured by means of a small float lowered by fishing line into the observation wells. When the line goes slack, the water has been reached. The float was inspected to make sure it was wet and did not hang up in the well. Then the depth from the pavement surface to the water surface was measured and recorded.

Figure 12: HOBO® data logger


Figure 13: HOBO® setup (HOBO® and spacers in the foreground and the tube that holds the setup is in the background)

Subsurface instrumentation consists of temperature sensors and moisture sensors. Figure 12 shows the typical temperature sensor. These are HOBO® data loggers manufactured by Onset. At each site, six of these loggers were placed in a sealed tube spaced out at depths of 6, 12, 18, 30, 54, and 78 inches as measured from the surface and illustrated in Figure 13. This was done in March of 2007. In December of 2008, three sensors were added to each site and the depths were changed to 6, 12, 18, 24, 36, 42, 54, and 78 inches. Temperatures were recorded once per hour and the data is downloaded about every six months.

Subsurface moisture sensors were installed in late 2007. Four sensors were placed at each site. The sensor depths ranged from 6 to 28 inches. In the summer of 2008, when the data from these sensors was being downloaded, it was evident that most of them had malfunctioned. The problems were traced to defective sensors and new moisture sensors were installed in April of 2009. The original sensors were not removed and the new sensors were placed within 3 feet of the original sensors and at the same depths. The data from the 2007 installations were investigated to determine if useable.

Surface instrumentation consists of a pavement surface temperature sensor, a temperature sensor at 18" below the surface, and a Davis® Weather Station. The pavement surface temperature sensors take the roadway surface temperature and the 18" subsurface temperature. The Davis® Weather Station and logging device records the wind speed, wind direction, air temperature, incoming solar radiation, humidity, and amount of precipitation at a set interval. The data from each weather station is downloaded periodically simultaneously with the data from the HOBO® sensors. Figure 14 shows a typical weather station installation.

Figure 14 Davis® Weather Station at North Groton Road

Figure 15 Pavement surface temperature sensor at North Groton Road

The weather stations were installed at the sites over a period of 6 months. The Rumney and Wentworth Sheds received their weather stations at the end of July 2007. The Kancamagus sites and North Groton Road received their weather stations at the end of September 2007. The Lake Tarleton weather station was installed in mid-October 2007. Stinson Lake and Warren Flats received their weather stations in mid-January 2008.

The weather stations are only useful to maintenance personnel if the data can be accessed in a timely fashion. With this consideration, a smaller project within this project linked 4 weather stations in District 2 to the NHDOT Road Weather Information System (RWIS) homepage so that the data can be accessed in real-time from the patrol shed computers. The existing weather stations at the Wentworth and Rumney shed sites were linked to the RWIS homepage, and the sheds at Enfield and Bristol each received a new weather station that has been linked to the RWIS homepage. Plymouth State University performed the networking of the weather stations and is monitoring them over the course of a year as part of an agreement with the NHDOT. An informal poll of the District 2 patrolmen showed that this RWIS data is being checked regularly by many of the patrolmen and the effort has proven to be useful.

Subsurface Data Collection

Frost and Water Table Depth

The frost depth and water table depth data have been collected for the thawing seasons of 2007-2009. During the thawing season of 2007, only frost tubes were available to collect the subsurface thaw measurements at all sites. This data is shown below.

Table 1 Frost and Water Data from 2007 Thawing Season (Frost Tube)

2006-2007 (frost tube)	Kanc 1	Kanc 2	Kanc 3	LT	NGR	RS	SLR	WF	WS
Max Frost Depth (in.)	63	65	59	46	48	56	40	36	61
Frost-out date*	5/10	5/10	5/10	4/30	4/20	4/2	4/20	4/30	3/30
Min Water Depth (in.)	45	n/a	67	29	58	112	13	31	119

*The frost out date represents the first date that the tube showed no frost. The actual date that the frost disappeared is sometime between this date and the date of the previous tube reading.

During the spring of 2007, HOBO sensors and frost tube were installed at all of the sites. The Kanc sites also have thermistors which were installed at the time the roadway was reconstructed in 2005.

HOBO sensors provide continuous data by recording temperature measurements once per hour. Because of this continuous stream of data, the sensors were used to determine the dates of frost-out for the purposes of this report. The sensors have a tolerance of ± .8°F; however, they were not calibrated prior to installation. Therefore, the data from each sensor was graphed, and the frost out date was determined as the point where the temperature increased after leveling out during a phase change from ice to water. This point was generally from 31ºF to 32.6º F. The dates at which the sensors indicated frost-out for each site in 2008 and 2009 are shown on graphs provided in the next section of this report.

The frost tubes were checked whenever the site was visited but sometimes it would be a gap of a week or more between site visits. The three different means of measuring the subsurface temperature (e.g. frost tubes, HOBO sensors, thermistors) resulted in discrepancies among the dates of complete thaw.

The winters of 2006-2007 and 2008-2009 were colder than the winter of 2007-2008, which explains the greater frost penetration during those two winters.

Table 2 Frost and Water Data from 2008 Thawing Season (HOBO Logger)

2007-2008	Kanc 1	Kanc 2	Kanc 3	LT	NGR	RS	SLR	WF	WS
Max Frost Depth (in.)	63.5	63.5	58	44	27	37.5	31	28	52
Frost-out date	4/25	4/11	4/29	4/10	4/9	3/22	4/2	3/13*	-
Min Water Depth (in.)	79	n/a	63.5	32	95	37.5	11.5	19	64
Max Water Depth (in.)	85	n/a	122	36	116	117	25.5	53	116

*This date is skewed to be early because of missing data.

Table 3 Frost and Water Data from 2009 Thawing Season (HOBO Logger)

2008-2009	Kanc 1	Kanc 2	Kanc 3	LT	NGR	RS	SLR	WF	WS
Max Frost Depth (in.)	65	62	61.5	49	44.5	60	43.5	32	-
Frost-out date	4/28	4/17	4/26	4/17	4/10	4/11	4/2	3/28	-
Min Water Depth (in.)	52	n/a	65	27	42	112	10.5	14	-
Max Water Depth (in.)	83.5	n/a	115.5	45	114.5	116	20	66.5	-

The dates of frost-out were generally a few days later in 2009 than in 2008. The dates from 2007 were from frost tubes and the late dates reflect both the severity of the winter and the difficulty in checking the frost tubes every day with the limited resources available.

The water tables were shallower in the spring of 2009 than in the two preceding spring seasons. This may be due to the fact that 2008 was officially the wettest year on record in Concord, New Hampshire and the melting of the heavy snowfall in 2008 and 2009. In 2007 and 2009, the water table at North Groton Road spiked dramatically in early to mid-April. It did not do this in 2008 and there is no explanation for the phenomena. At Warren Flats, Lake Tarleton, and Stinson Lake Road, there would be periods when the water table was shallower than the frost as indicated by both the HOBOs and the frost tubes. We have no explanation for this other than possible melt water sitting on top of a layer of impermeable frozen soil. Full records of the frost tube and water table measurements are in Appendix B. HOBO graphs are available in Appendix B.

The subsurface and climatic data collected from the sites was/is being used by Richard Berg, a researcher hired by the Forest Service, to calibrate the EICM. The data being summarized and developed into input data for calibration of the EICM includes pavement profiles, hourly weather data, and water table depth. An input file is being developed and tweaked for each site so that the EICM predicts the observed conditions at each site. The 2008 data is being used for the calibration and tweaking and data recorded in 2011 will be used for confirmation of the results. ARA, the firm contracted by the USDA Forest Service to develop the EICM –based prediction model, is also working on developing a stand-alone input file driven stiffness predictor for each site. This should be ready by the winter of 2010-2011 and will be highly useful for maintenance personnel.

Dick Berg has also been working on developing a NHDOT version of the Washington DOT/Minnesota DOT/FHWA "Cumulative Degree Day" procedure for predicting when a road will thaw. Data collected under this project was used to modify the current procedure. This work is summarized in the white paper *Initial Analysis of the New Hampshire Spring Load Restriction Procedure* submitted by Robert A. Eaton et al. (2009) to the ASCE Cold Regions Engineering Conference.

Pavement Deflection Data Collection

Pavement deflection data is important in the formation of correlations between roadway conditions and roadway strength. Prior to the start of the 2008 thawing season, the use of a Falling Weight Deflectometer (FWD) owned by Worcester Polytechnic Institute was obtained through a rental agreement. The FWD used was a Dynatest 8002 lightweight FWD. The FWD is trailer mounted and towed behind a van.

Figure 16 Worcester Polytechnical Institute's FWD

The FWD applies an impact force to the roadway and then measures maximum deflections at various points resulting from the impact. A weight is allowed to fall onto a load plate that rests on the pavement. The distance the weight is allowed to fall, and the magnitude of the weight allows the operator to vary the impact to whatever force is desired. The deflections are measured by sensors that are in contact with the pavement at set distances from the load plate. The number of sensors and the distance from each sensor to the load plate are variable. The vertical deflections are measured in mils (1 mil

= .001 in.). For comparison purposes, the average credit card is 0.03 inches thick so the pavement is not moving very much even though the numbers may look large.

FWD Testing Configuration

The particular setup used for the testing on this project was four load levels and an arrangement of nine sensors. The four load levels were 6 kips, 9 kips, 12 kips, and 16 kips. Three drops were made at each load level at each of the stations at each site. The deflections for the three drops at each load level were averaged to get an average deflection for each load level. The 9 kip load level simulates the loading from the dual wheels on one side of the American Association of State Highway and Transportation Officials [AASHTO] Equivalent Single Axle Load (ESAL) of 18 kips. The area of the load plate is equivalent to the contact area of the dual wheels. The nine sensors were in a fixed arrangement that was used for every test site. The spacing from the center of the load plate is provided in Table 4.

Figure 17 Sensors and the load plate of the FWD

Sensor	Spacing (in.) (plate to sensor)
1	0
2	7.6
3	11.7
4	17.7
5	23.9
6	35.9
7	47.7
8	59.6
9	71.7

Table 4 FWD sensor spacing

The sensor setup and load levels used approximate the National Strategic Highway Research Program (SHRP) Long Term Pavement Performance Program (LTPP) FWD protocol. The position of sensor 9 is different than what is recommended by the LTPP protocol. It is the furthest away from the load plate instead of being near the load plate but on the opposite side as the rest of the sensors. Prior to the start of testing for each year, the FWD was taken to the national calibration center run by the Pennsylvania DOT in Harrisburg, PA for reference calibration of the load cell and sensors. The FWD sensors were relative calibrated at the NHDOT during the middle of the 2008 and 2009 testing seasons by NHDOT Research personnel and found to be within tolerances.

Each day, before the start of testing, at least one buffer warm-up sequence was performed. This is a series of two drops each at load levels of approximately 6 kips, 10 kips, 14 kips, and 19 kips. On colder days when temps were below 30° F, the buffer warm-ups were often performed at each site and multiple times at the first site of the day. This was done to warm up the rubber buffers and the hydraulic system that operates the FWD. Additionally, the sensor holders were lubricated with a silicone spray and the lubrication of the moving parts and cables on the FWD was checked. The FWD was rinsed as needed when coated with slush.

Figure 18 Rinsing slush off of the FWD

Observations from FWD Testing at the Sites

The FWD testing was conducted in the same manner for the thawing seasons of 2008 and 2009. The FWD testing, to establish frozen conditions, was conducted in late February and testing during thawing conditions took place from March until June. Tests were taken in October to establish "normal" unfrozen baseline conditions. As testing progressed, observations were recorded about the conditions at each site and the effects on the readings.

As the roadways thawed out, a common occurrence at the District 2 sites was that a transverse crack between sensors or a longitudinal crack near the row of sensors would cause data repeatability warnings from the FWD program. If this occurred, the FWD test was restarted. The second time, the FWD test was continued and the data was accepted. In the case of an out-of-range error, which happened if the deflection was over 80 mils, the test at that particular station was terminated.

During the 2009 testing, damage to the FWD from an operator error in late March resulted in two periods of downtime for repairs. Subsequently, data collected was not as extensive as that collected during the 2008 thawing season. The weakest thawed conditions may have been missed at the Stinson Lake and Lake Tarleton sites. It was decided to proceed with testing after the damage occurred in hopes that the damage did not cause the FWD's load cell to be out of tolerance. The sensors underwent relative calibration after the incident and were found to be within tolerance. The FWD was reference calibrated again in June of 2009 to check that the load cell was still within tolerance after the damage and repairs. The load cell was confirmed to still be within tolerance.

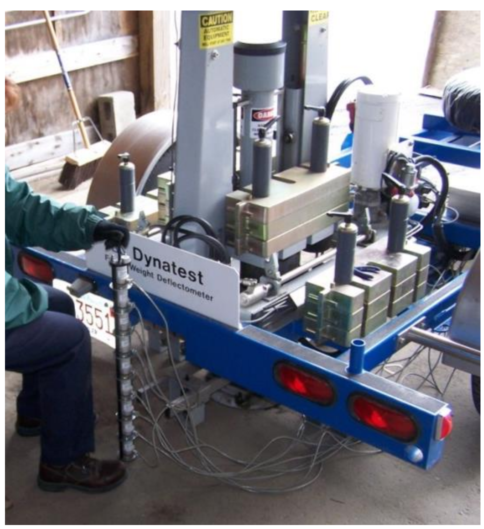


Figure 19 Relative Calibration of the FWD

Kancamagus Highway (Kanc) Sites-NH 112

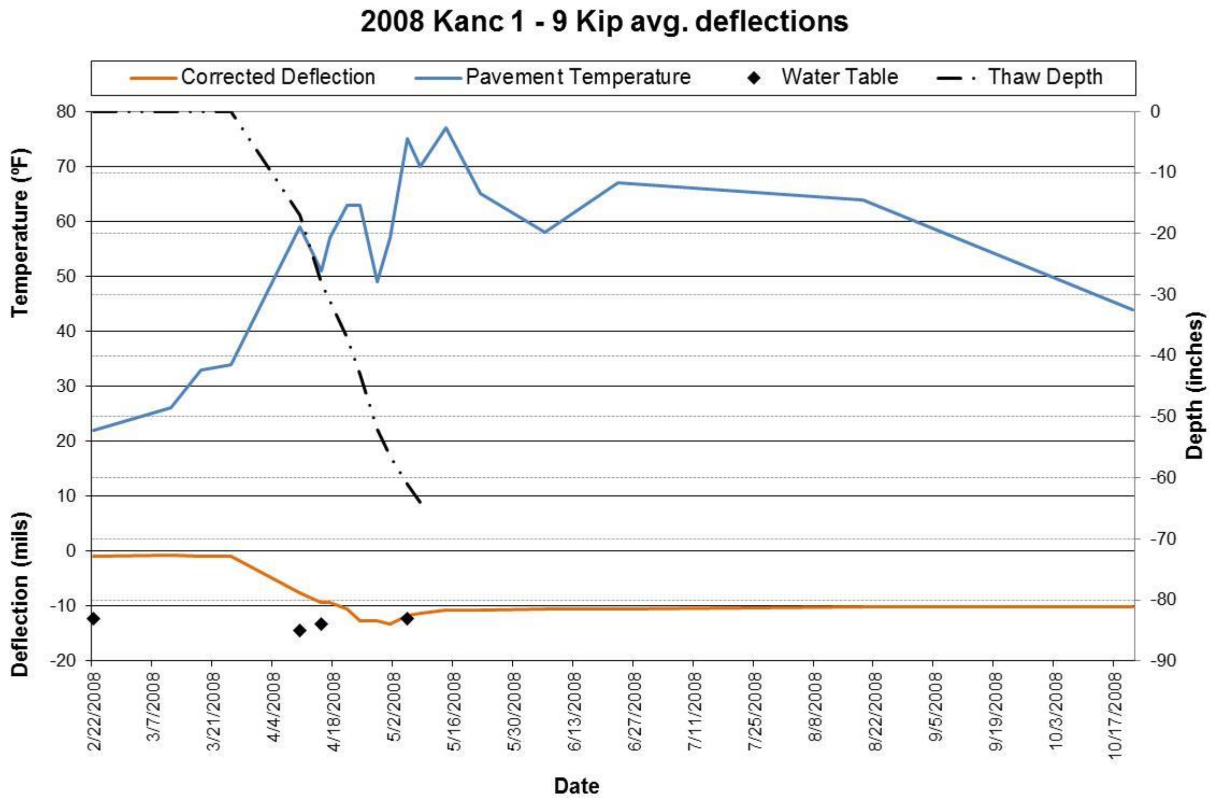
The Kanc sites were much stronger roadways than those in District 2. This was expected because of reconstruction and reclamation work in 2005. There were not any pavement cracks at the three sites and the FWD readings could be taken without incident. All exhibited the same behavior of losing stiffness to a certain point as they thawed, and then rebounding a minimal amount and leveling out. The reconstructed section at Kanc 1 proved to be the stiffest by a marginal amount over the other two sites. Kanc 2, the reclaim with cement stabilization, was slightly stiffer than Kanc 3, the regular reclaim. Thawing at the Kanc sites lagged behind the District 2 sites by about a month due to the more severe winters at the Kanc. The temperatures were always lower than those in District 2, and the snowfall was much heavier. In 2008, the snowbanks at the Kanc sites were higher than the roof of the 1-ton van that was used to tow the FWD. Normal thawed condition readings were taken with the FWD in October.

Figure 20 FWD testing at Kanc 2 on February 2008

In 2009, Kanc 1 and Kanc 2 tested very similarly to 2008 testing. Kanc 3 sustained its maximum deflection on April 8 almost a full month earlier than in 2008. Its next maximum deflection was April 14th. Table 5 and Charts 1 and 2 provide the 2008 and 2009 deflection data for the Kanc sites.

Table 5 Kanc Site Deflection Data

Season	2008		2009	
Deflection (mils)	Max	Normal	Max	Normal
K1	13.2	10.1	11.8	10.6
K2	16.9	11.6	14.0	11.2
K3	18.6	14.3	20.2	14.2


2008 Kanc 1 - 9 Kip avg. deflections
Corrected Deflection
Pavement Temperature
Water Table
Thaw Depth
Temperature (ºF)
Deflection (mils)
Depth (inches)
Date
80
70
60
50
40
30
20
10
0
-10
-20
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
2/22/2008
3/7/2008
3/21/2008
4/4/2008
4/18/2008
5/2/2008
5/16/2008
5/30/2008
6/13/2008
6/27/2008
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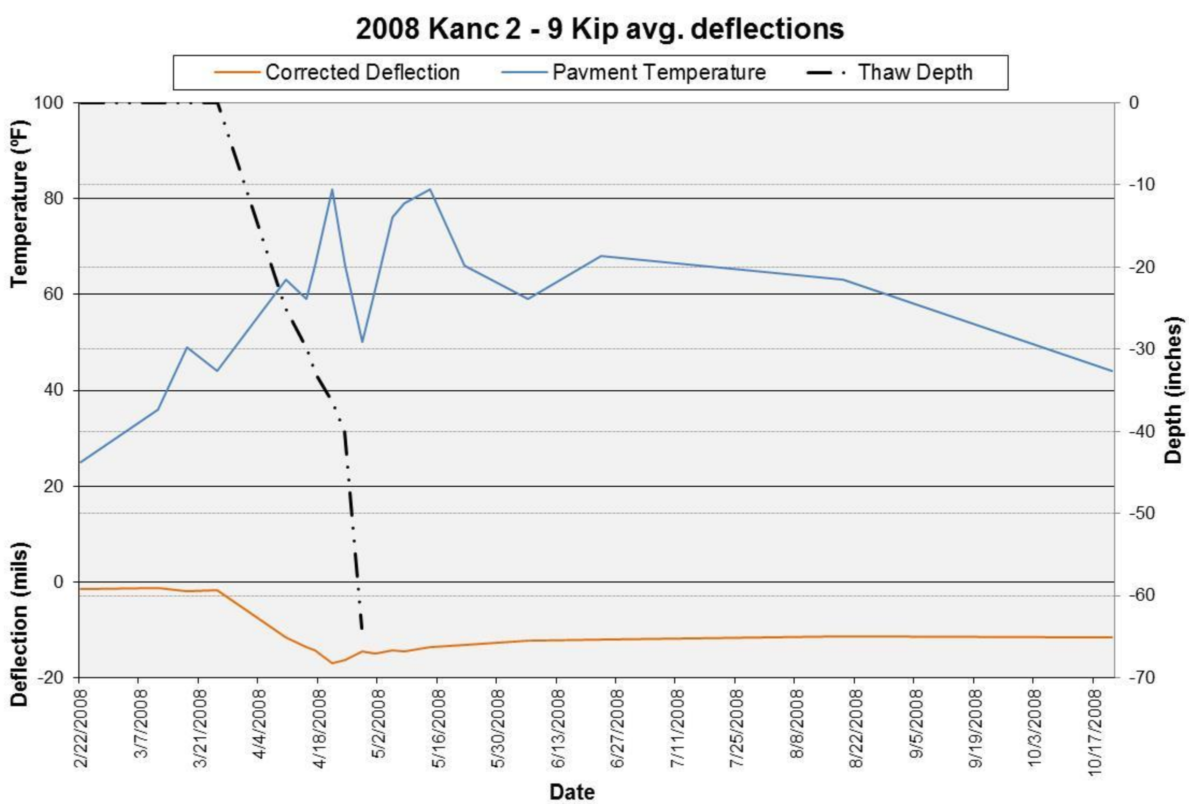
8/8/2008
8/22/2008
9/5/2008
9/19/2008
10/3/2008
10/17/2008


2008 Kanc 2 - 9 Kip avg. deflections
Corrected Deflection
Pavment Temperature
Thaw Depth
Temperature (ºF)
Deflection (mils)
Depth (inches)
Date
100
80
60
40
20
0
-20
0
-10
-20
-30
-40
-50
-60
-70
2/22/2008
3/7/2008
3/21/2008
4/4/2008
4/18/2008
5/2/2008
5/16/2008
5/30/2008
6/13/2008
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10/3/2008
10/17/2008

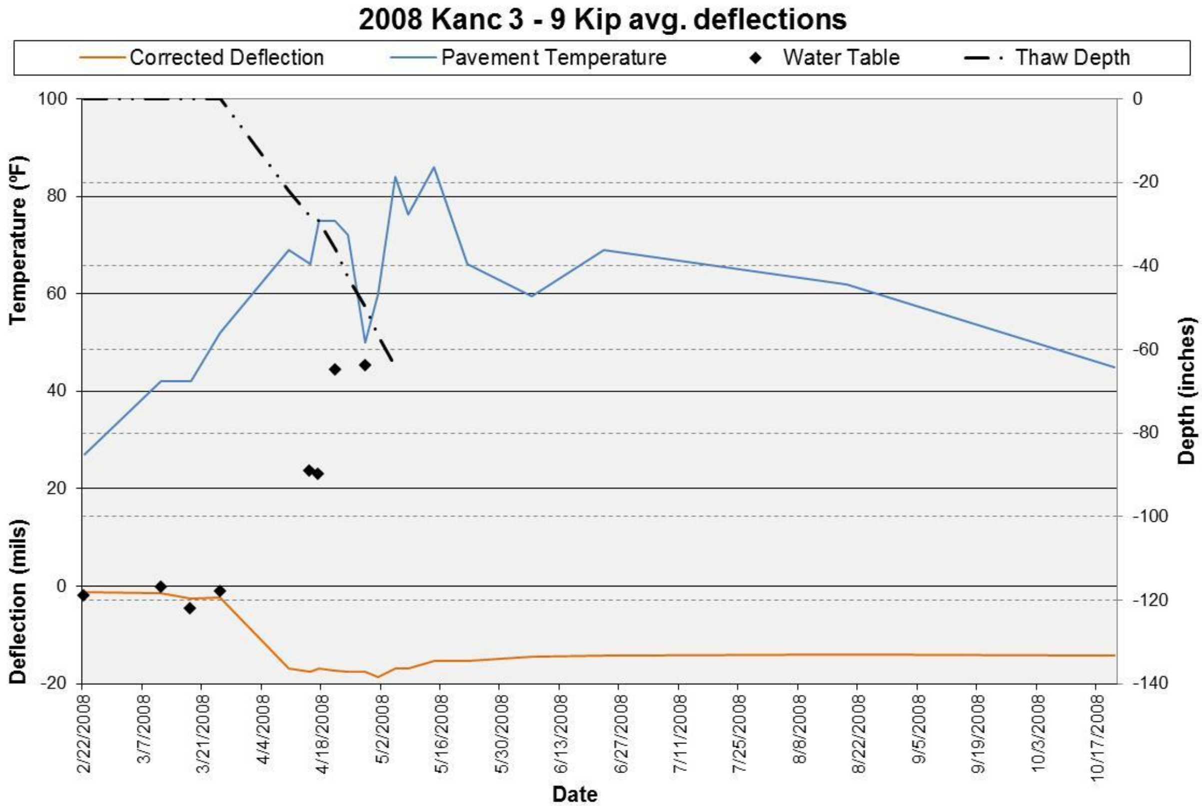
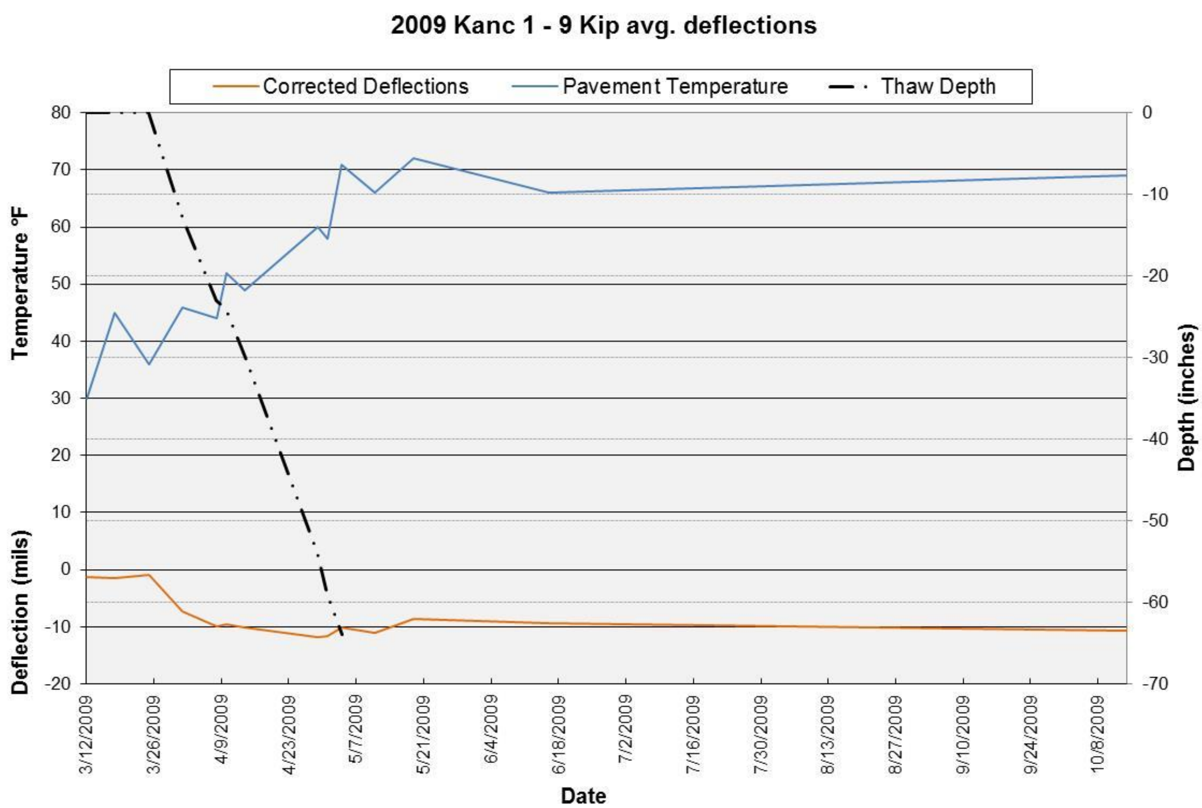
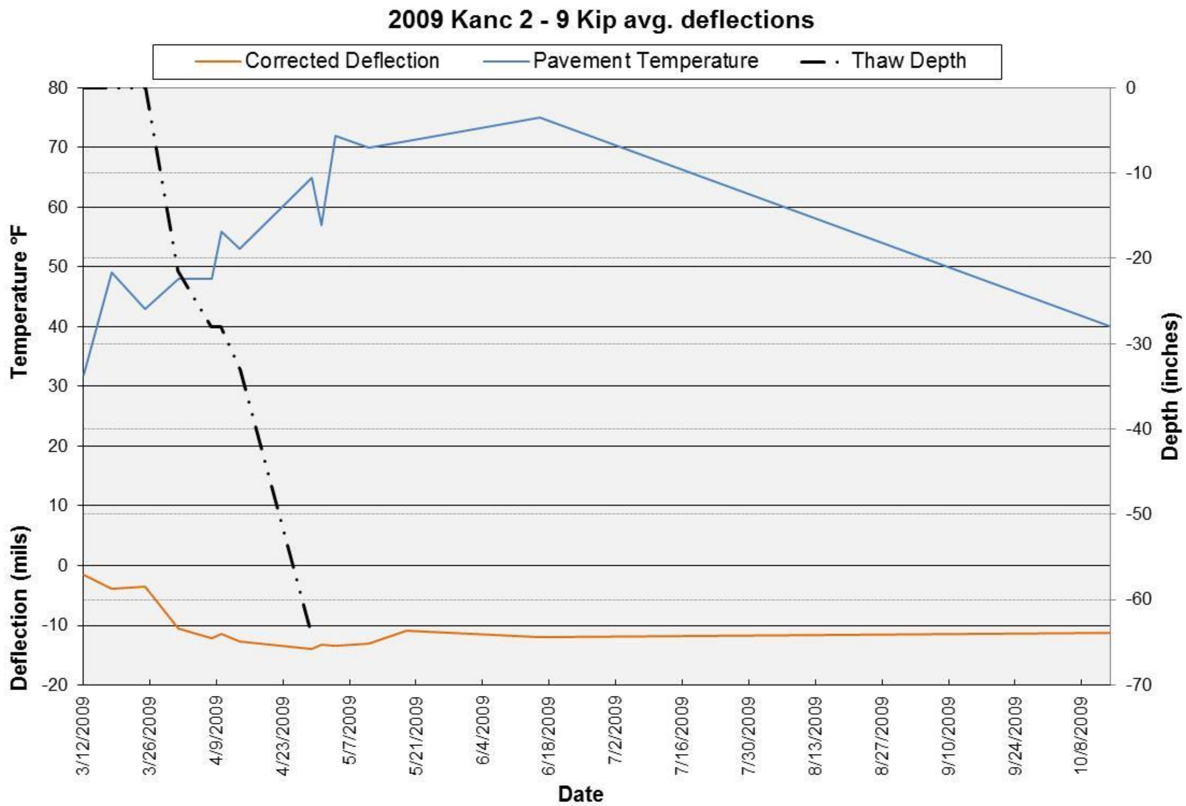


Chart 1: Kanc Sites1, 2, and 3 in 2008





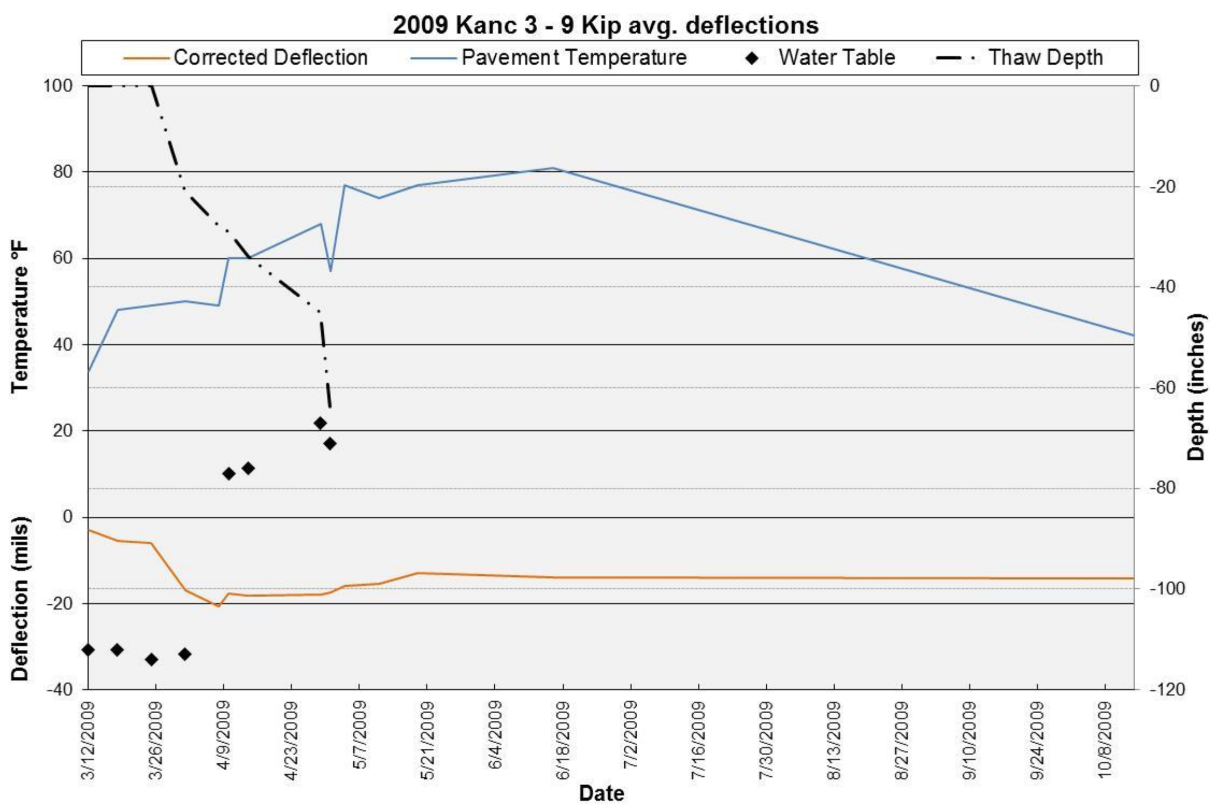


Chart 2 Kanc Sites 1, 2, and 3 in 2009

Stinson Lake Road

Despite having a shallow water table, overall, this was the stiffest site in District 2. There were occasional ‘repeatability’ errors, but never any ‘out-of-range’ errors. The site had a minor amount of cracking compared to most of the other District 2 sites. In 2008, there were no noticeable differential frost heaves and even though the road was posted, this was lifted while the road was still in a weakened state.

In 2009, the site tested similarly to 2008. It remained the stiffest site in District 2 and there was no differential heaving or increase in noticeable cracking. In 2009, the road was not posted. The weakest point may have been missed due to the FWD being down for repairs in mid-April. Table 6 and Charts 3 and 4 provide the data for the deflections at this site.

Figure 21 Late February 2008 at Stinson Lake Road

Table 6 Deflection Data for Stinson Lake Road

Season	2008		2009	
Deflection (mils)	Max	Normal	Max	Normal
	30.7	19.0	25.9	20.0

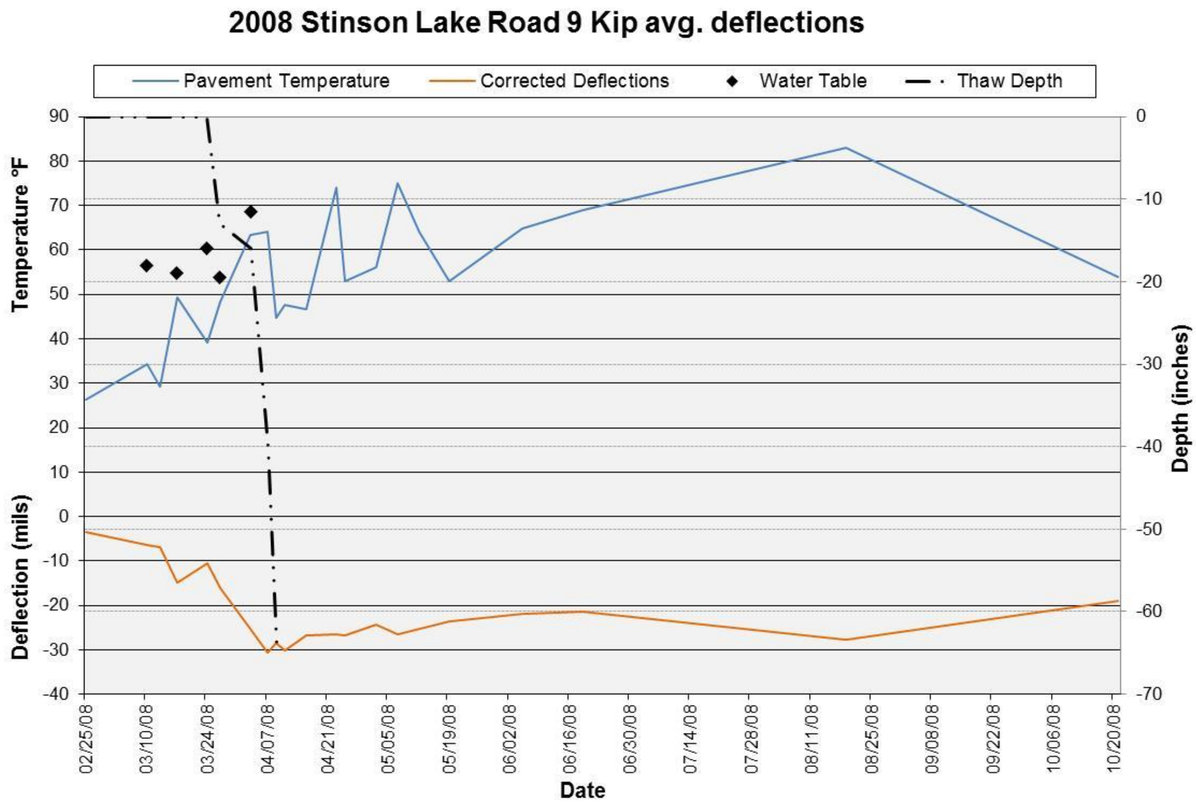


Chart 3 Stinson Lake Road in 2008

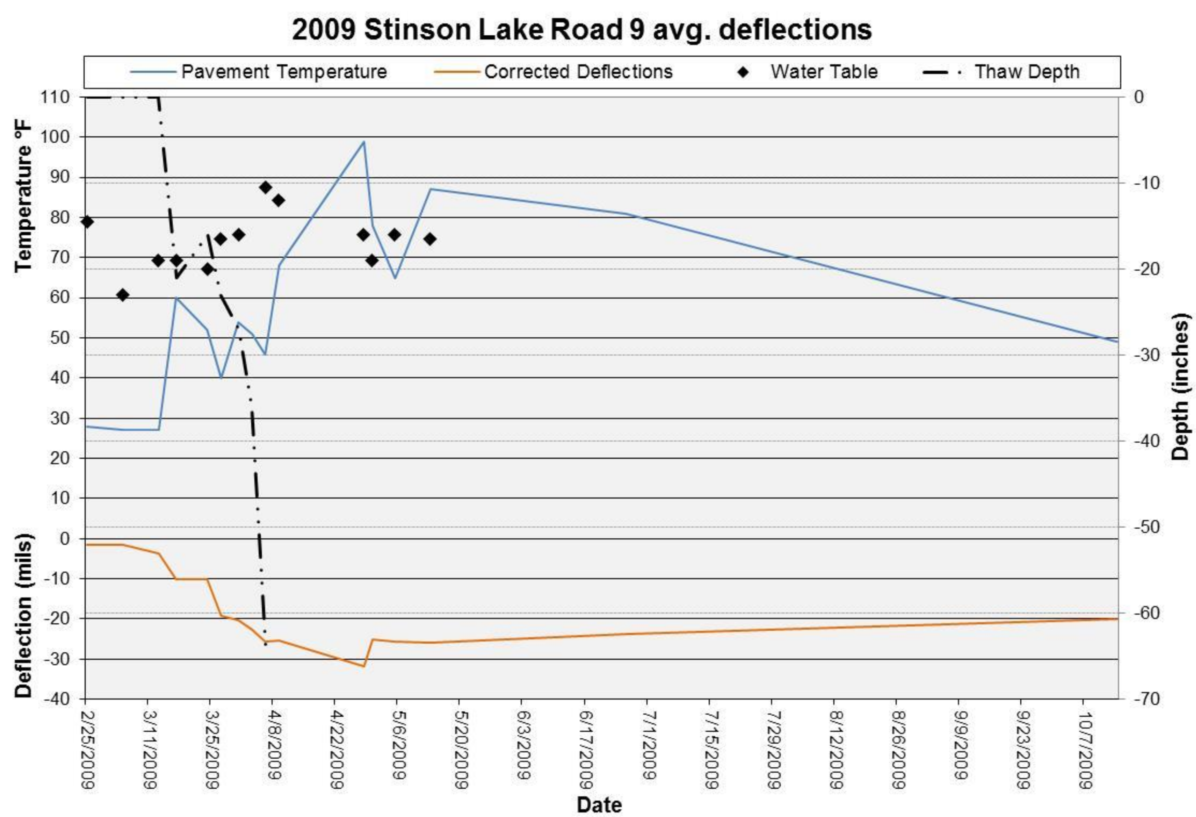


Chart 4 Stinson Lake Road in 2009

North Groton Road

This site had the least cracked pavement of the District 2 sites. The road did not differentially heave here in either 2008 or 2009, and only one station had a crack that interfered with the sensors. In 2008, there was water standing in the ditchline immediately adjacent to the site during the middle of April, indicating saturated conditions or a frozen layer even though the water table was never measured shallower than 90 inches. During this period, the 16 kip loading from the FWD would produce out-of-range errors. The site's maximum deflection occurred during this time period. This road was posted during the 2008 thawing period and the postings for the road were also removed at about the site's weakest point as illustrated in the graph.

There was water in the ditchline at various times in 2009, but it did not stand there like it did in 2008. There were no out-of-range errors in 2009. The water table spiked here up to a depth of 20 inches during mid-April for no apparent reason. One possible explanation is that water somehow got trapped in the measuring hole. The road was not posted in 2009. Table 7 and Charts 5 and 6 provided the data for the deflections at this site.

Figure 22 Standing water in ditchline alongside of North Groton Road site in April 2008

Figure 23 The FWD is over the last station at the North Groton Road site

SEASON	2008		2009	
DEFLECTION	MAX	NORMAL	MAX	NORMAL
	59.5	22.6	46.8	26.8

Table 7 Deflection Data for North Groton Road

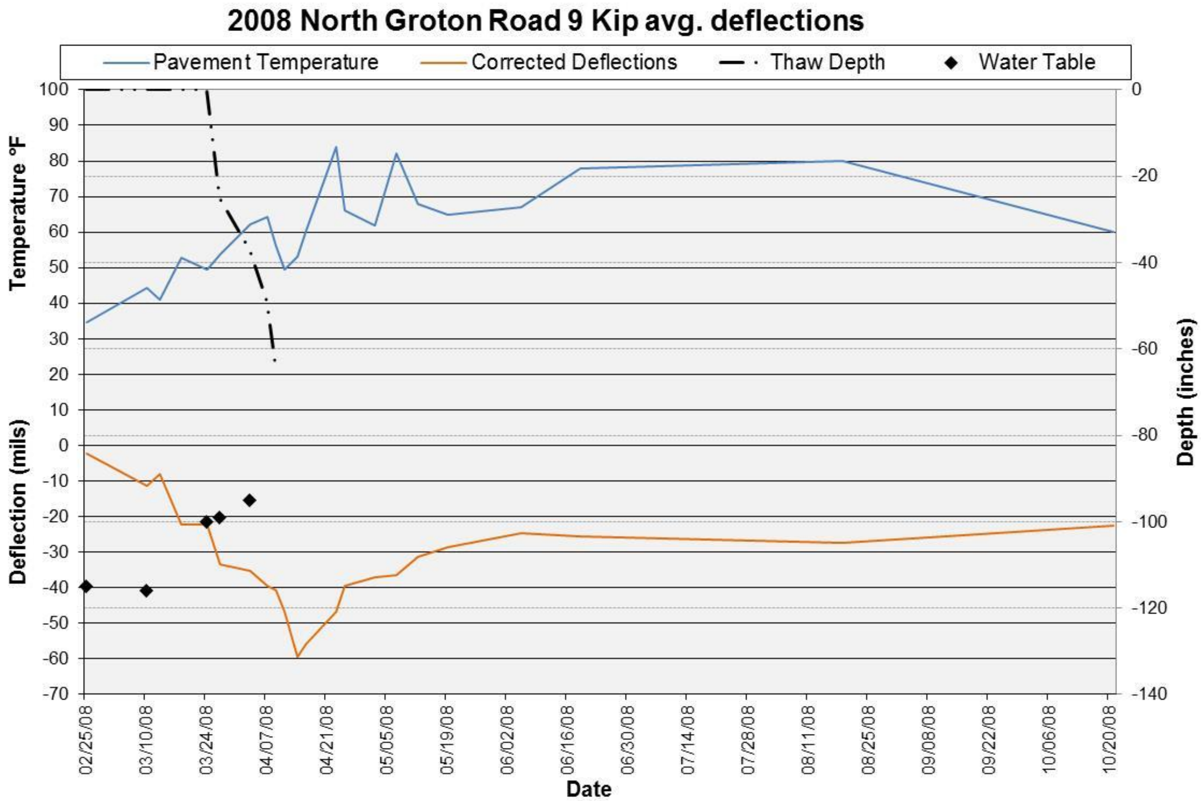


Chart 5 North Groton Road in 2008

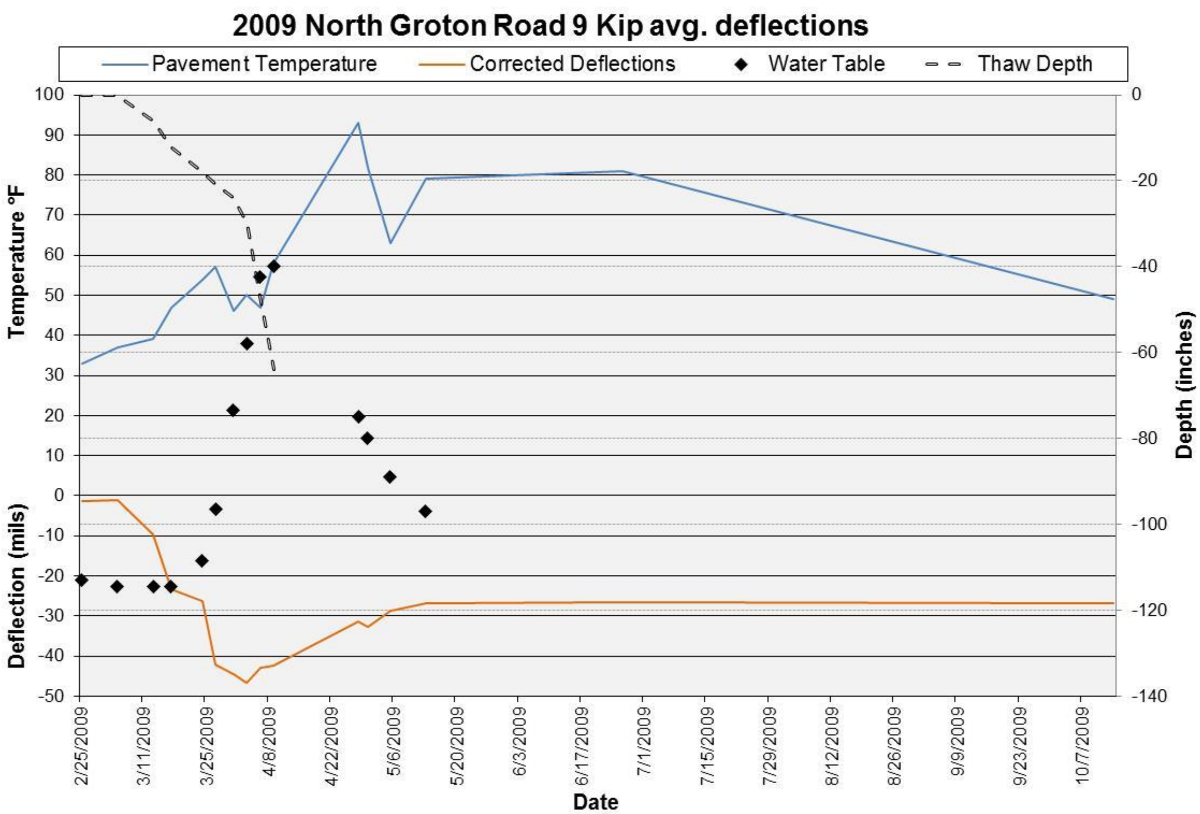


Chart 6 North Groton Road in 2009

Rumney Shed

This site had the second worst pavement of all of the District 2 sites. The site is in the driveway to the shed and has heavy block cracking throughout Stations 1-7. Station 4 is in a trench patch and because of its settled condition is unusable by the FWD. Stations 8-10 are over various shims and overlays of pavement that have been placed on the driveway and the pavement is in much better shape than at Stations 1-7. The difference was quite evident when testing was taking place and in the data analysis. Due to numerous repeatability and out-of-range errors encountered at Stations 1-7, the data analysis for the site was conducted with data collected from testing at Stations 8-10. Unfortunately, the FWD broke down at this site during the October 2008 test, so "normal" values were not recorded.

In 2009 the site behaved very similarly and as in 2008, only Stations 8-10 were used. The October test was conducted successfully in 2009. Since the site is in a shed driveway it was not posted in either year. Table 8 and Charts 7 and 8 provide the deflection data for this site.

Figure 24 Rumney Site showing the difference in pavement conditions between Stations 6 and 7 in the foreground and Stations 8-10 in the background. The FWD is on Station 10.

Figure 25 Showing the difference in pavement condition between Rumney 6 (left) and Rumney 8 (right)

SEASON	2008		2009	
DEFLECTION	MAX	NORMAL	MAX	NORMAL
	43.0	n/a	44.9	34.4

Table 8 Deflection Data for Rumney Shed

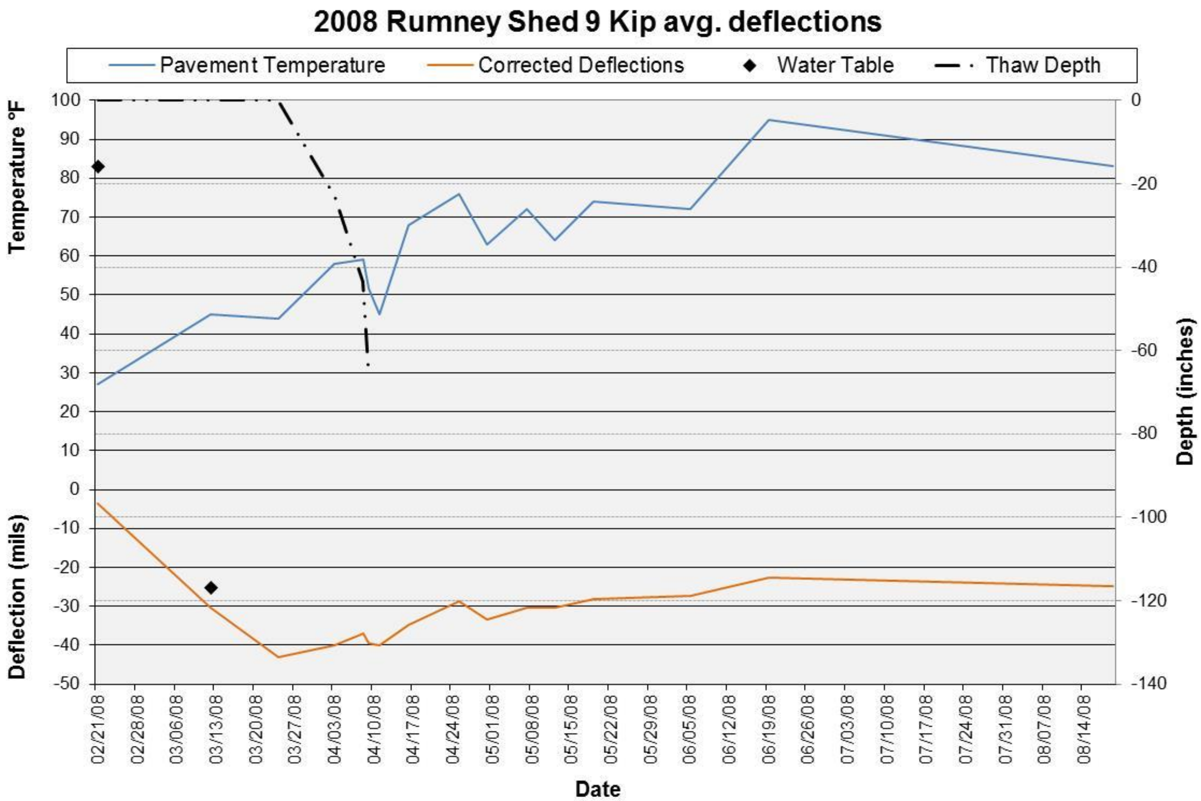


Chart 7 Stations 8-10 at Rumney Shed in 2008

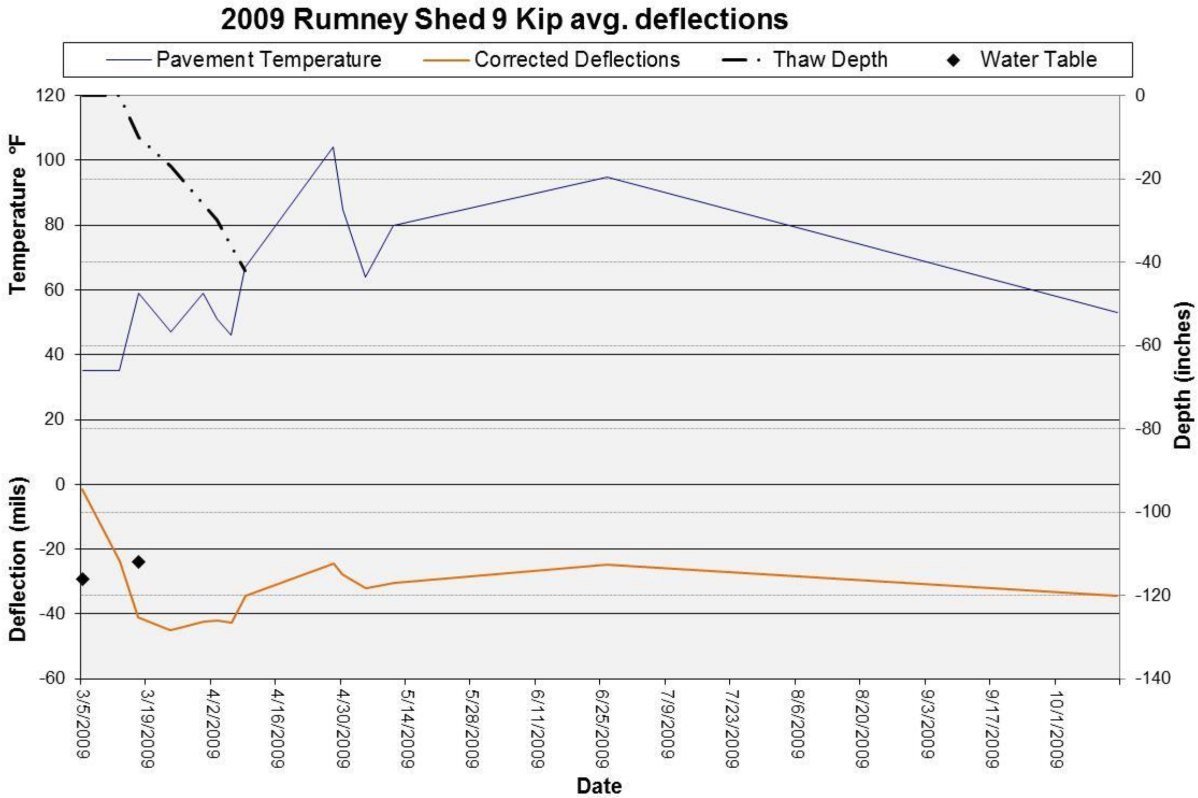


Chart 8 Stations 8-10 at Rumney Shed in 2009

Wentworth Shed

This site had the worst pavement of all of the District 2 sites. It was heavily cracked except for where trench work for the new gas pumps had resulted in repaving of a portion of the site. After a few attempts at testing during thawing conditions, the decision was made to abandon this site because the heavy cracking and puddled water were causing numerous time-consuming FWD errors and restarts. Relative movement between the independent chunks of pavement was actually visible during one attempt.

Figure 26 Heavy cracking typical at Wentworth shed site

Warren Flats

In 2008, this site exhibited such severe differential frost heaving that occasionally some of the stations were inaccessible to the FWD because not all of the sensors could touch the pavement when the array was lowered (Figure 27). From early to mid-March the frost heave action appeared to be at its worst. In early March, a vertical step of 3 inches formed at a crack in the left wheel path at about the midpoint of the site (Figure 28). This crack was shimmed with sand and the differential recessed as the season progressed. The postings at this site were posted on March 10 and lifted on April 16 about a week after the largest deflection even though the road was still in a weakened state.

Figure 27 Sensors not touching uneven pavement at Warren Flats

Figure 28 Three-inch differential heaving at Warren Flats

In the summer of 2008, a paver shim treatment was placed at the site. Crack sealing did not take place before the shim and almost all of the major cracks reflected back through the shim by the time we started 2009 testing. The site again revealed excessive frost heaving. The frost layer was a foot deeper and the water table rose to 14 inches below the surface as opposed to 19 inches below the surface in 2008. Even though this season's testing included the paver shim treatment, the site was not as stiff as in 2008. This illustrates that this treatment did not contribute much to strength as the existing cracks reflected through. Table 9 and Charts 9 and 10 provide the deflection data for this site.

SEASON	2008		2009	
DEFLECTION	MAX	NORMAL	MAX	NORMAL
	48.2	17.4	53.8	24.7

Table 9 Deflection Data for Warren Flats

Figure 29 Warren Flats site in August of 2008 shortly after being shimmed

Figure 30 Warren Flats site in the spring of 2009 with heavy reflective cracking through the shim and the same heaving problems

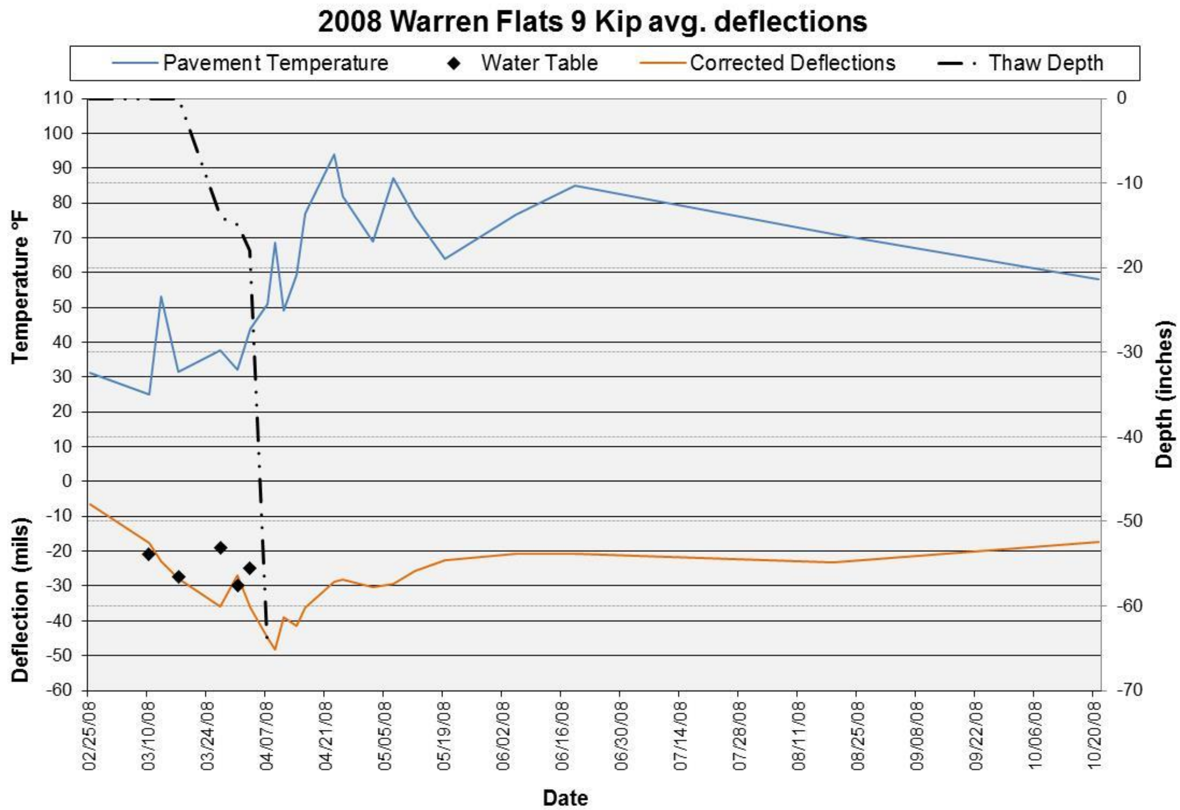


Chart 9 Warren Flats Site in 2008

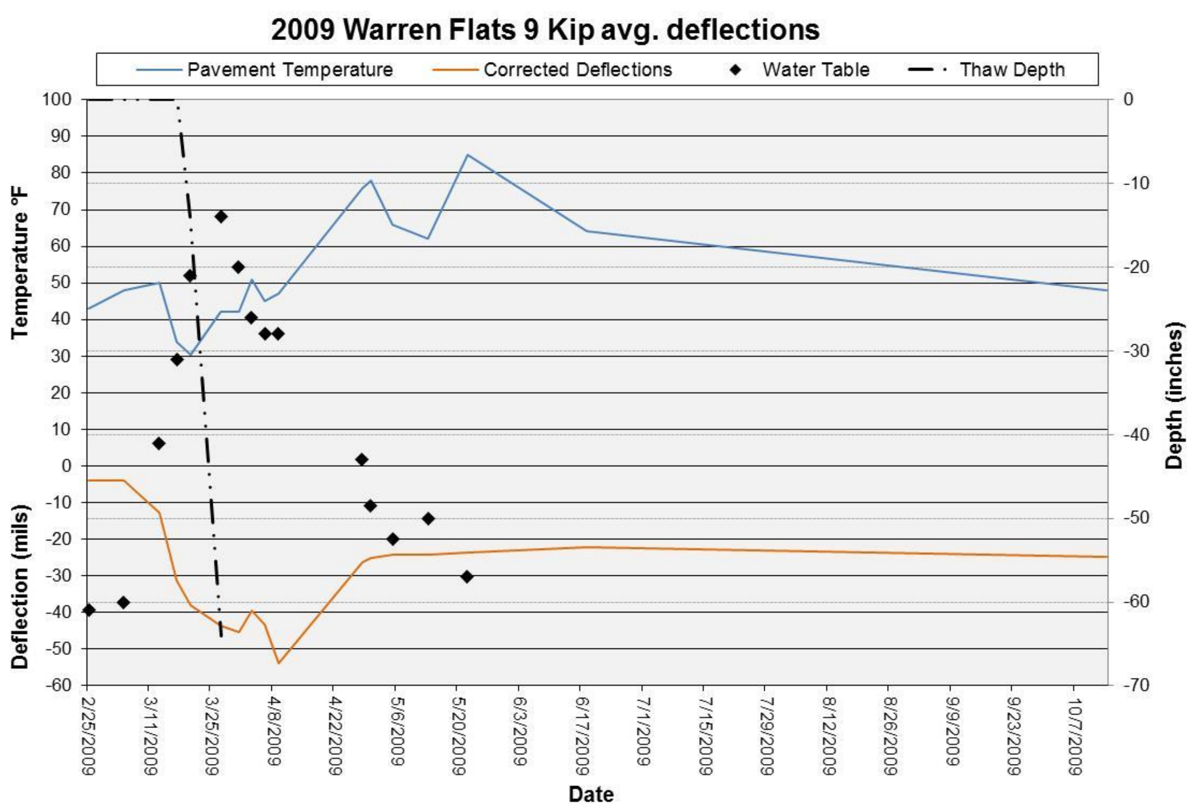


Chart 10 Warren Flats Site in 2009

Lake Tarleton

This site had several pavement cracks that were documented but the pavement did not heave as badly as Warren Flats. There is a culvert crossing almost 100 feet away from the testing area and it picked up the vibrations from the FWD. The vibrations were evidenced by the ripples forming in the pool at one end of the culvert. There was a longitudinal crack offset about a foot from Stations 7 through 10 (Figure 31) and obviously affected the readings at these stations. There were many times when the 16 kip load could not be used here due to the “out-of-range” deflection errors. The maximum deflection readable by the sensors is 80 mils and several times the 12 kip load would cause deflections in the 70-mil range. During the weakest period, the difference in movement from the FWD loaded side of the longitudinal crack to the unloaded side of the crack was visually detectable. The site was posted on March 10 and lifted on April 16.

Sections of this site received a paver shim in the summer 2008. In 2009, the site tested similarly to 2008. The pavement cracks reflected through the shim and the longitudinal crack offset from Stations 7-10 again affected the non-frozen state readings. The weakest period may have been missed here due to FWD downtime. Table 10 and Charts 11 and 12 provide deflection data for the site.

Figure 31 Longitudinal crack at Lake Tarleton running alongside Stations 7 to 10

SEASON	2008		2009	
DEFLECTION	MAX	NORMAL	MAX	NORMAL
	51.3	31.2	34.2*	33.4

Table 10 Deflection Data for Lake Tarleton

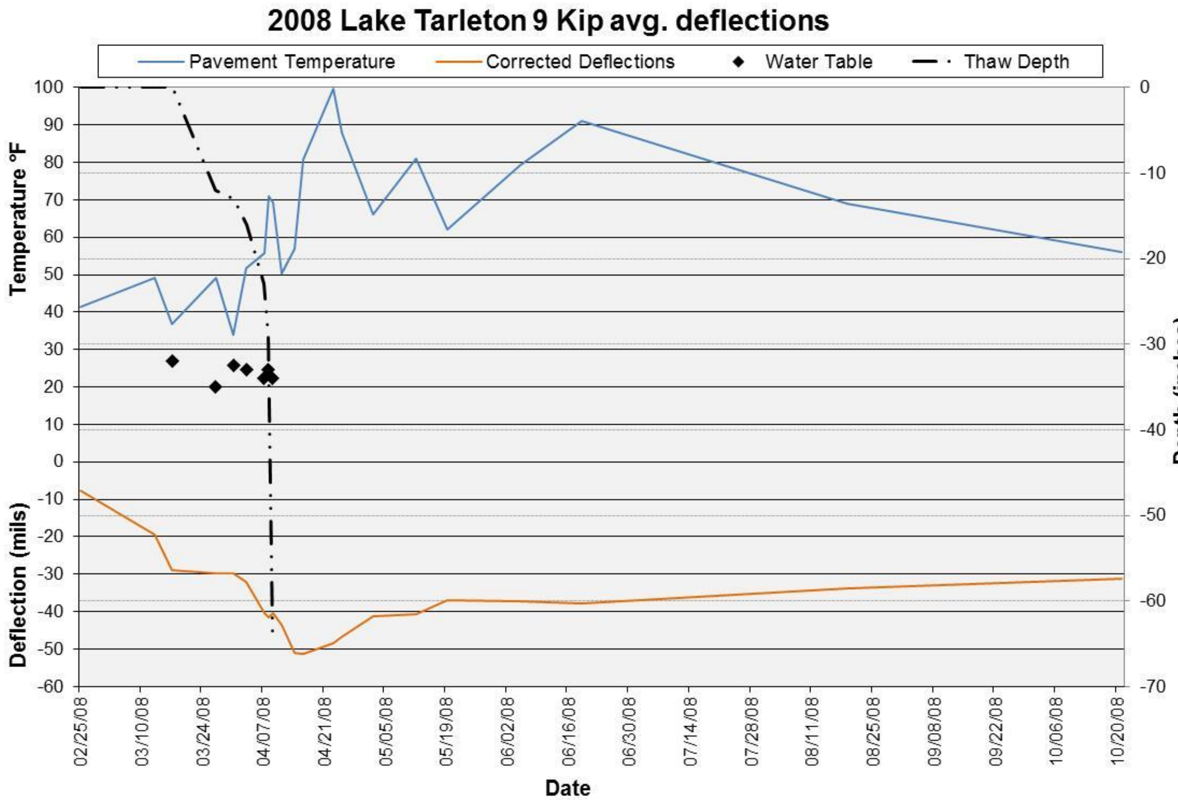


Chart 11 Lake Tarleton Site in 2008

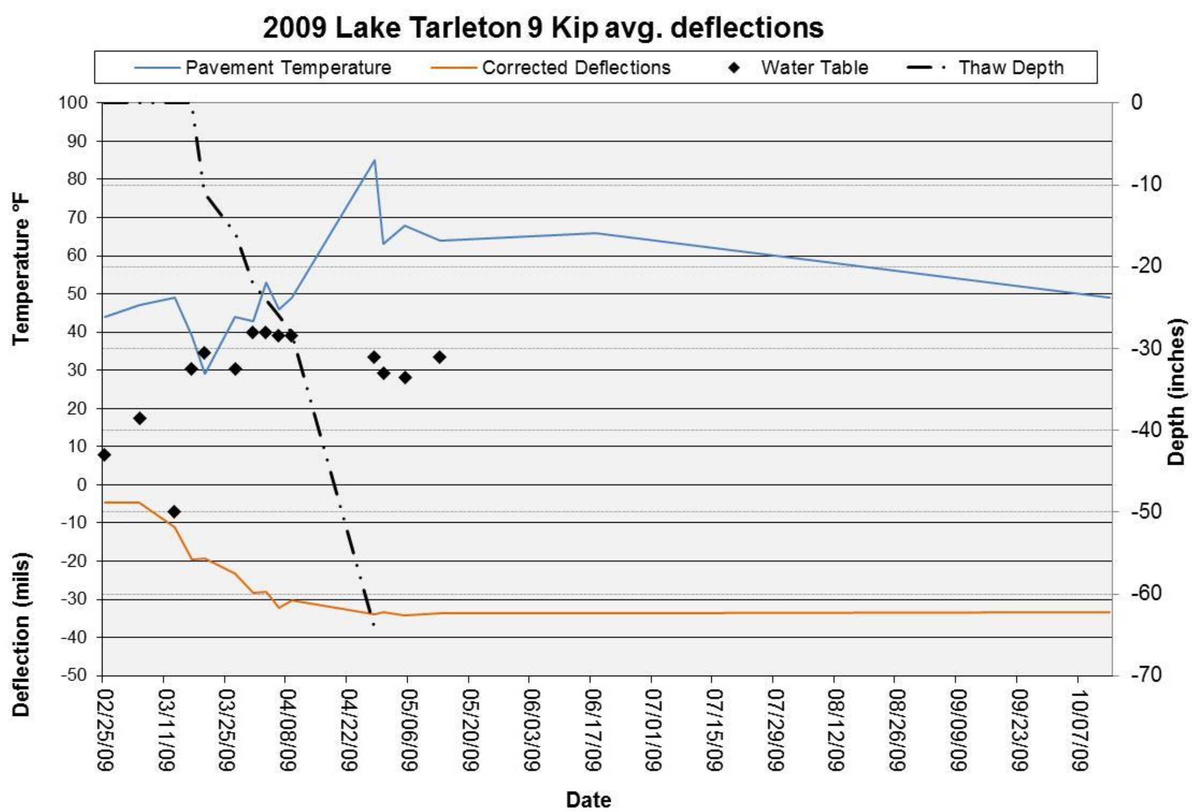


Chart 12 Lake Tarleton Site in 2009

Summary and Conclusions

This project set out to relate weather and subsurface conditions to roadway strength and to validate a computer application to help predict subsurface conditions based on weather forecasts. Over three years, from 2007 to 2009, a large amount of data was collected. Some general observations have been made, although much of the data still needs to be analyzed. The clear conclusion is that a properly constructed road with good drainage is a much stronger road during thawing conditions than the rather. This was demonstrated by the difference to which the weather and subsurface conditions affected the Kanc sites versus any of the District 2 sites.

The Kancamagus Highway sites were originally built in mid-1960 and then either fully reconstructed or rehabilitated in 2005. The engineer designed Kanc sites did not have cracked pavement, have a deep water table, and are located on well-drained soils that decrease the frost susceptibility. These characteristics contribute to the fact that at wettest conditions, pavement strength was generally equal to or better than any District 2 site during dry conditions. The sites all transitioned from frozen to a weakened condition then rebounded by 3 or 4 mils to their normal condition. This magnitude of the weakening and rebound was much less than what was observed in District 2. A point of further interest would be to compare any FWD readings taken before the 2005 reconstruction with FWD readings taken after the reconstruction.

The project led to some general observations supported by data about the thawing season on New Hampshire roadways. These bulleted observations listed draw relationships between the weather, subsurface conditions, and roadway strength.

- Subsurface thawing can progress quite rapidly

In several instances, the frost tubes showed several inches of frost lost in a day. As an example, Lake Tarleton recorded frost from 29 to 39 inches on April 8, 2008 and recorded none on April 9, 2008. At Kanc 2, which has different soils than Lake Tarleton, 12 inches of frost was lost between April 24 and April 28 of 2008. Lake Tarleton lost 6 inches of frost between April 14 and 15 of 2009.

- Weakest point of the roadway (as measured by FWD) does not coincide with the point of complete thaw

Table 11 shows that in almost all cases, the maximum recorded deflection from FWD testing was after the date that the HOBOs recorded the frost out.

	2008			2009		
Site	Max. Def/Date		Frost Out Date	Max. Def/Date		Frost Out Date
Kanc 1	13.21	5/1	4/25	11.81	4/29	4/28
Kanc 2	16.87	4/21	4/11	13.97	4/29	4/17
Kanc 3	18.61	5/1	4/29	20.55	4/8	4/26
Lake Tarleton	51.31	4/16	4/10	34.20	5/5**	4/17
North Groton Rd.	59.55	4/14	4/9	46.76	4/3	4/10
Rumney Shed	43.02	3/24	3/15*	44.90	3/24	4/11
Stinson Lake Rd.	30.66	4/7	4/2	25.66	5/5**	4/2
Warren Flats	48.23	4/9	3/13	53.76	4/9	3/28

Table 11 Dates of Maximum Average Deflections vs. Frost Out Date

*In 2008 only the 18" HOBO recorded and the frost tube was inaccessible so frost out was after this date

**Maximum Deflection was most likely missed due to FWD downtime; weakest point was probably between 4/9 and 5/5.

- Roadway surface condition is important to roadway strength

The Rumney Shed site illustrated this dramatically. Stations 1-7 of this site were all located on heavily cracked pavement. Stations 8-10 were located on pavement that had much less cracking and the FWD deflections were consistently less at these stations. The maximum average deflection at the site, when all stations were included, was 51 mils vs. 43 mils for the maximum average deflection of stations 8-10. At the Lake Tarleton and North Groton Road sites, the deflections were greater at the stations near pavement cracks.

- Strength recovery in District 2 lagged the frost out by about five weeks

The charts for the District 2 sites show that in both 2008 and 2009, the roadways recovered most of their "normal" strength by five weeks after the frost-out date. The Rumney Shed site recovered in less than five weeks in both years. The Rumney Shed was the best well-drained of the District 2 sites. With melted frost quickly draining away, recovery was quicker. It appears to reasonable, in review of this data, that five weeks after frost out could be set as a general timeframe for lifting postings.

Soil moisture data is a key factor in making correlations between saturation levels and roadway strength. The subsurface moisture sensors were not discovered to be defective until it was too late to replace them for the 2009 thawing season. If the moisture sensors had been working correctly, the 2009 FWD testing might have been very revealing as to the interaction between the various soil types, the moisture levels, and the timeline of the thaw.

This project did not attempt to develop a method of correlating different levels of stiffness to damage from loading and we would recommend research on developing a method.

Enhanced Integrated Climatic Model (EICM) Prediction Program

The USDA Forest Service contracted with Applied Research Associates to calibrate and develop the EICM into a subsurface condition prediction model. The data collected in 2008 was used to calibrate the EICM model in late 2009 in order that the model would give a close approximation of the observed subsurface conditions in 2008. The data collected during the 2009 season has yet to be compared to what the calibrated model would have predicted for that year. The beta version of the calibrated EICM prediction model was finished in late 2010. There were some problems in the beta version which caused it to be difficult to run on some computers scheduled to be upgraded. In the spring of 2011, testers hired and coordinated by the USDA Forest Service will test the revised beta version against real observations. It is anticipated that the finished program should be available by the end of 2011.

Future Work Needed

The project did not yield enough data to be able to provide concrete conclusions as to when to lift the restrictions; however, the data provided by this project and the EICM program being developed by this project will become major building blocks in the process of developing a tool to determine when to lift the restrictions. The ultimate vision is an automated program that roadway managers will be able to utilize and select appropriate information for their decision making process. The finished tool would need large-scale resources, such as a pooled fund project, to advance the data collected and the EICM prediction tool into the finished product for maintainers.

The Minnesota DOT Office of Materials and Road Research (MnRoads) has developed a tool that is similar to the vision for this project. MnRoads has a website that graphically depicts the present state of load restrictions across the state.
htttp://www.mrr.dot.state.mn.us/research/seasonal_load_limits/sllindex.asp

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Robert A. Eaton, Richard L. Berg, Andrew Hall, Heather J. Miller, and Maureen A. Kestler (2009) Initial Analysis of the New Hampshire Spring Load Restriction Procedure. Cold Regions Engineering 2009: pp. 532-545. doi: 10.1061/41072(359)52

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Appendix A

Water Table and Frost Tube Data

Date	Kanc 1		Kanc 2		Kanc 3		Stinson Lake		North Groton		Rumney Shed		Wentworth Shed		Lake Tarleton		Warren Flats	
	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost
1/18/2007								12	91	17		15	122	15	36	24	51	15
1/26/2007	75	42		32	112	31							120	30	40	29	53	21
2/1/2007							37		111	27	117	44	122	42	44	32	62	24
2/7/2007													125	49	75	35	51	26
2/12/2007	81	62		45	121	48							121	48				
2/22/2007														60	71	41	44	32
2/28/2007														61	42	42	45	33
3/12/2007													120	61	47	44	46	32
3/14/2007							31	41	118	48	122	56					72	34
3/16/2007	81	63		12-65	121	15-59							120	8-59	46	10-34	72	34
3/20/2007							26	40	118	48	118	53		59				
3/21/2007	83	63		65	122	59							122	59	36	46	68	36
3/23/2007														13-46		16-31		14-21
3/26/2007														27-54	36	20-26	48	18-28
3/30/2007														GONE	37	19-42	42	14-27
4/2/2007	83	17-63		24-64	DRY	25-59	19	33	113	21-44	117	GONE	119		37	24-45	39	23-33
4/9/2007	83	21-63		26-62	121	28-60	21	26-34	109	22-41	112				35	24-44	43	20-27
4/20/2007							12	GONE	58	GONE								
4/24/2007	45	44-63		37-57	75	42-58									29	57-58	31	51-52
4/30/2007	60	56-63		44-52	68	49-59										GONE		GONE
5/4/2007	83	60-63		53-56	67	53-58												
5/10/2007	83	GONE		GONE	75	GONE												

Table 12 2007 Water Table and Frost Tube Readings

Date	Kanc 1		Kanc 2		Kanc 3		Stinson Lake		North Groton		Rumney Shed		Wentworth Shed		Lake Tarleton		Warren Flats	
	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost
1/24/008							26	27	114	27			64	32	33	35	53	20
1/31/2008	79			45	119	47							116					
2/22/2008	83	62		55	119	52												
2/26/2008									115									
3/10/2008		64		64	117	57	18	32	116							44	21	28
3/12/2008														52				
3/17/2008							19	31							32	44	28	27
3/18/2008		63		64	122	58												
3/24/2008		63		64	118	58	16	31	100				118	55-56	36	42	32	13-26
3/27/2008							20	13-29	99	35					35	12-42	19	15-25
3/31/2008															33	13-41	30	15-24
4/3/2008							12	16-28	95	25-31	117	23-38		GONE	33	17-40	25	18-24
4/4/2008															33	19-40	19	GONE
4/5/2008															34	20-39		
4/7/2008															34	23-40		
4/8/2008															33	29-39		
4/9/2008								GONE		GONE		GONE			34	GONE		
4/10/2008		17-63		25-62		22-58												
4/15/2008	85	28-63		30-60	89	28-58												
4/17/2008	84	31-63		33-59	90	29-57												
4/24/2008		43-62		40-52	65	43-56												
4/28/2008		52-62		GONE	64	50-56												
5/5/2008	83	61-62				GONE												
5/7/2008		GONE																

Table 13 2008 Water Table and Frost Tube Readings

Date	Kanc 1		Kanc 2		Kanc 3		Stinson Lake		North Groton		Rumney Shed		Wentworth Shed		Lake Tarleton		Warren Flats	
	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost
12/2/2008	84	20		18	99	17												
12/4/2008									104									
2/5/2009	85	65		59	116	57	14	37	113	8			120+	60	45	42	67	30
2/18/2009													61		39	45	63	32
2/26/2009							15	42	114						43	46	61	32
2/27/2009															33	46	63	33
3/5/2009							23	41	115	41					39	47	60	32
3/12/2009		64+		62+	112	60												
3/13/2009							19	44	112	45		56			50	33	41	32
3/17/2009							19	40	115	12-45	116	10-54			33	42	31	32
3/18/2009	52	64+		62+	112	60		21-38		13-44		12-60						
3/19/2009								20-40		15-44		14-53		18-59	33	14-47	31	13-32
3/20/2009															31	11-47	21	14-32
3/23/2009								15-38		22-44		17-53			35	13-47	21	18-31
3/24/2009							20	16-36	109	22-45					33	13-47	29	17-30
3/25/2009	59	64+		62+	114	61												
3/27/2009							17	23-35	97	27-43					33	16-46	14	GONE
3/30/2009															32	26-51		
3/31/2009							16	27-34	74	GONE	112	26-47			28	22-47	20	
4/1/2009	61	13-64+		22-62	113	21-61												
4/2/2009															29	23-50	26	
4/4/2009															27	29-46		
4/6/2009							11	GONE	42						29	27-44	28	
4/7/2009															28	28-45		
4/8/2009	55	23-64		28-61		28-61									29	32-45		
4/9/2009							12		40						29	29-44	28	
4/10/2009	58	24-64		28-60	77	29-61									30	29-44		

Table 14 2009 Water Table and Frost Tube Readings thru April 10, 2009

	Kanc 1		Kanc 2		Kanc 3		Stinson Lake		North Groton		Rumney Shed		Wentworth Shed		Lake Tarleton		Warren Flats	
Date	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost	Water	Frost
4/13/2009															31	32-33	38	
4/14/2009	55	30-63		33-62	76	34-60									34	34-43	41	
4/15/2009															34	36-42		
4/16/2009															33	GONE	44	
4/24/2009	79	42-63		41-53	63	45-60												
4/27/2009	82	50-63		45-49	65	48-59												
4/28/2009							16		75						31		43	
4/29/2009	83	54-64		GONE	67	52-59												
4/30/2009							19		80						33		49	
5/1/2009	84	59-64			71	GONE												
5/4/2009	84	GONE																
5/5/2009							16		89						34		53	
5/11/2009	83				78										30		46	
5/13/2009							17		97						31		50	
5/19/2009	83				85													
5/22/2009															34		57	

Table 15 2009 Water Table and Frost Tube Readings from April 13-May 22, 2009

Appendix B

Moisture Sensor Locations

Test Site	Date Installed	Depth	Data Logger Number
Rumney Shed	9/7/2007	5"	EM 3143
		9"	
		20"	
		36"	
North Groton Road	10/16/2007	7"	EM 3139
		16"	
	[4/21/2009]	22"	{EM 4767}
		28"	
Lake Tarleton	10/17/2007	11.5"	EM 3144
		15.5"	
	[4/17/2009]	17"	{EM 3418}
		22"	
Warren Flats	10/22/2007	11.5"	EM 3137
		14.5"	
	[4/17/2009]	22"	{EM 3023}
		30"	
Wentworth Shed	10/22/2007	5"	EM 3140
		13.5"	
	[4/22/2009]	20"	{EM 2732}
		24"	
Kanc 1	10/25/2007	7"	EM 3136
		14"	
	[5/1/2009]	20"	{EM 4983}
		25"	
Kanc 2	10/25/2007	9"	EM 3141
		12"	
		17"	
		22"	
Kanc 3	10/25/2007	10"	EM 3138
		13.5"	
	[5/1/2009]	18"	{EM 4982}
		24"	
Stinson Lake	11/1/2007	10"	EM 3142
		13"	
	[4/21/2009]	19"	{EM 1708}
		28"	* Could not install 28" WT @ 12"

[ ] Date New Sensors Installed { } New Data Logger Serial Number

The Kanc 2 and Warren Flats original sensors appeared to be good. No new sensors were installed at Kanc 2, but new ones were installed at Warren Flats as a check with the "older" ones. This meant no sensors were available for the Rumney Shed site.

Appendix C

Project Work Plan

Work Plan: Spring Thaw Predictor & Development of Real Time Spring Load Restrictions

SP&R Research Project No. 14282K

Purpose: The purpose of this two-year project is to develop a Real-Time Spring Load Restriction Methodology for the NHDOT. The methodology is intended to guide Maintenance Districts in their management of spring load restrictions by identifying the beginning and duration of the spring thaw period. Two methods will be used to determine how long load restrictions will be needed after the date of actual thaw: frost tubes readings and forecasting by computer model.

Plan of Work:

1. The NHDOT Maintenance District 2 will locate, instrument, and conduct testing at a total of five road sites and two shed sites.
   a.) Four road sites will be in the Rumney and Wentworth sections,
   b.) The fifth will consist of three cement-stabilized reclaimed test sections on Route 112 in Albany near the Saco Ranger Station and Bear Notch Road, which will be considered a single road site, and
   c.) The Rumney Shed 203 and the Wentworth Shed 202.
2. A Benkelman Beam will be purchased and a testing truck setup with constant weights, sign packages, etc.
3. Five weather stations will be purchased and installed at the Rumney Shed, Wentworth Shed, North Groton Road (Rumney Section) test site, the Lake Tarleton (Route 25C Wentworth Section) test site, and the Route 112 site in District 3. Arrangements will be made with Plymouth State University (PSU) Meteorology Department to allow the NHDOT staff to coordinate with PSU and access their weather data [possible tie in with RWIS data]. Weather data will be read every 20 minutes and downloaded to shed computers and to District 2 on a weekly basis. Data collection will include ambient air temperature, pavement surface temperature, pavement subsurface temperature (18” depth), wind speed and direction, precipitation rate and amount, and incoming solar radiation.
4. Subsurface temperature and moisture sensors, frost tubes, and water wells will be installed at all road sites and the shed sites. All but frost tubes already exist at the Route 112 site in District 3.
5. All instrumentation will be installed prior to November 30, 2006.
6. Deflection testing points will be located and baseline [pre-freeze] testing done before freeze-up.

7. Benchmarks will be set and level surveys of the test points will be monitored for amount of frost heave.
8. Photo documentation will be done throughout the project.
9. The Forest Service will continue their work with a modeler to continue with the Enhanced Integrated Climatic Model (EICM), which is embedded in the new Mechanistic Empirical Pavement Design Procedure (MEPDG). It is proposed to use the EICM (isolated from the MEPDG) with 10 day forecast temperatures to predict thaw. This will be done as follows: YEAR 1: a.) Select test sites. b.) Record subsurface temperatures 2-3 times a week at the test sites during anticipated spring thaw. c.) On those same dates, record the 10-day weather forecast. d.) Compare calculated date of thaw (using EICM & weather forecast) with date of thaw from test sections. YEAR 2: a) Use results from Year 1 (which we have reason to believe will be successful). b) Add user friendly front end to the isolated EICM model via contract using a EICM / MEPDG programmer to enable future use of thaw prediction model from one's office.
10. After the second year of testing, the final report will be published.

Work Force:
NHDOT District 2 forces will select the sites; oversee, coordinate, and install the instrumentation; conduct the testing; do the surveying; monitor the performance; and prepare the draft reports (except the modeling portion and falling weight report).

The Forest Service will do the modeling and forecasting. They will prepare the draft and final report for the modeling part of the project done by ARA.

NHDOT M&R will provide the drill rig to install the subsurface instrumentation (frost tubes, water wells, and pavement temperature and moisture sensors). NHDOT M&R will prepare and administer a two-year contract for the EICM model to predict thaw.

NHDOT Communications will assist with weather station installation.

NHDOT OIT will be involved as necessary for weather station data collection and download to the District 2 Office.

Schedule:

September 18, 2006 TAG Meeting at District 2 Office 12:00 Noon – 2:00 PM.

Fall 2006 Purchase and install instrumentation and conduct baseline testing. NHDOT M&R will contract Year 1 with ARA/Greg Larson.

Fall 2006–Summer 2007 Conduct testing.

Fall 2007 Review Project.

Fall 2007-Summer 2008 Conduct testing. NHDOT M&R will contract with Greg Larson to complete Thaw Prediction Model and prepare final report on its use.

Summer 2008 Draft final report

Costs: Estimated cost of the project is $67,800.

Benkelman Beam	$ 2,200.
Weather Stations 5 @ $1,800.	$ 9,000.
Frost Tubes 25 @$80.	$ 2,000.
Subsurface Temp. & Moisture Sensors 1 set per site x 7	$21,000.
Data collection equipment (data loggers, etc.)	$ 7,000.
ARA Contract Year 1 ($10.k) Year 2 ($15.k)	$25,000.
Miscellaneous (including 1 water well per site)	$ 1,600.
Total Project Estimate:	$67,800.

Implementation: The research findings will be shared with the Highway Maintenance Bureau through distribution of the published report. If products/procedures prove to be feasible and cost effective, formal presentations will be made to familiarize affected managers within DOT and the T2 center with the benefits of their use. A poster will be created to be displayed at appropriate events.

Approval

Technical Advisory Group Sponsor: ______________________ Date:
Alan Hanscom

Technical Advisory Council Chair: ______________________ Date:
Alan Rawson

Appendix D

Roadway Drill Logs For Instrumented Sites

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

New Hampshire DOT

PROJECT NAME **STATEWIDE 14282K** BRIDGE NO. N/A
DESCRIPTION Spring Load Restriction Research

BORING NO. **B1**
SHEET NO. 1 OF 1
STA. OFF.
BASELINE NH Route 112
ELEVATION (ft) 1228.4
START/END 12/6/06 / 12/6/06
DRILLER P. Huckins (NHDOT)
INSPECTOR Doug Rogers
CLASSIFIER DRR
EAST/NORTH (ft) 1072791/544594

GROUNDWATER

DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE	S	NW	Pavement
SIZE I.D. (in)	1.375	3	6.0
HAMMER WT. (lb)	140		
HAMMER FALL (in)	30		
HAMMER TYPE	Automatic		

DRILL RIG: CME 45 Truck

DEPTH (ft)	STRATUM CHANGE DEPTH (ft)	STRATUM CHANGE ELEVATION (ft)	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0							-PAVEMENT- (0.3' top coat over 0.25' of reclaim/cement mix)
	0.6	1227.9	81, 72, 48, 45/0.4	S1	1.7 [87]	0.6 – 2.5	Very dark greyish brown and black, coarse-fine sandy GRAVEL, some-little silt, w/ traces of asphalt
	1.2	1227.2					Yellowish brown, gravelly MEDIUM-FINE SAND, some coarse sand, little-trace silt -FILL-
			31, 29, 20, 27	S2	1.4 [70]	2.5 – 4.5	Greyish brown-brownish grey, MEDIUM-FINE SAND, some gravel, some coarse sand, little silt over 2" layer of dark brown and dark grey, FINE SAND, little medium sand
	3.4	1225.0					Dark yellowish brown, MEDIUM-FINE SAND, little-trace silt
5			21, 25, 24, 50	S3	1.4 [70]	4.5 – 6.5	Dense, dark yellowish brown, MEDIUM-FINE SAND, little silt, trace coarse sand, w/ isolated weathered cobble -GLACIAL OUTWASH-
			28, 21, 14, 18	S4	0.9 [45]	6.5 – 8.5	Dense, yellowish brown and dark yellowish brown, COARSE-FINE SAND, little-trace gravel over gravelly COARSE-FINE SAND (from 7.0')
			15, 14, 13, 11	S5	1.3 [65]	8.5 – 10.5	Light brownish grey, MEDIUM-FINE SAND, trace coarse sand
	9.0	1219.4					Dense, very severely weathered, coarse-grained, GRANITIC ROCK Note: most likely weathered bedrock
10							Bottom of Exploration @ 10.5 ft (El. 1217.9)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS

Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS

Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

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Kanc Site 1 Boring Log

TEST BORING REPORT		BORING NO. B9
STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION	New Hampshire DOT	SHEET NO. 1 OF 1 STA. ___ OFF. ___
PROJECT NAME STATEWIDE 14282K	BRIDGE NO. N/A	BASELINE NH Route 112
DESCRIPTION Spring Load Restriction Research		ELEVATION (ft) 1228.4

GROUNDWATER						EQUIPMENT	SAMPLER	CASING	CORE
DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE	TYPE	S	NW	Pavement
						SIZE I.D. (in)	1.375	3	6.0
		NR				HAMMER WT. (lb)	140	DRILL RIG	
						HAMMER FALL (in)	30	CME 45 Truck	
						HAMMER TYPE	Automatic		

START/END 12/11/06 / 12/11/06
DRILLER P. Huckins (NHDOT)
INSPECTOR Doug Rogers
CLASSIFIER DRR
EAST/NORTH (ft) 1074157/543966

DEPTH (ft)	STRATUM CHANGE (ft) DEPTH	STRATUM CHANGE (ft) ELEVATION	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0							-PAVEMENT- (0.4' top coat, 0.35' reclaim/cement mix)
	0.8	1227.7					
	1.4	1227.0	19 17 14 15	S1	1.4 [70]	1.0 - 3.0	Brownish grey, gravelly COARSE-FINE SAND, little-trace silt Dense, dark yellowish brown and dark greyish brown, MEDIUM-FINE SAND, some-little silt, some-little coarse sand, little gravel
	3.6	1224.8	12 9 7 7	S2	1.4 [70]	3.0 - 5.0	Grey-brownish grey, MEDIUM-FINE SAND, little coarse sand, little silt, little-trace gravel Dark brown-very dark greyish brown, silty FINE SAND, some coarse-medium sand, trace gravel, trace organics
5							-FILL-
	5.6	1222.8	6 17 14 13	S3	1.3 [65]	5.0 - 7.0	Yellowish brown, COARSE-FINE SAND, trace silt
			13 14 14 13	S4	1.1 [55]	7.0 - 9.0	Dense, greyish brown, COARSE-FINE SAND, little-trace silt, trace fine gravel over brownish grey, FINE SAND, little-trace medium sand, little-trace silt -GLACIAL OUTWASH-
10			7 8 11 11	S5	1.1 [55]	9.0 - 11.0	Medium dense, brownish grey, FINE SAND, little medium sand, little-trace silt w/ 2" layer of very dark reddish brown medium sand at 9.7'
							Bottom of Exploration @ 11.0 ft (El. 1217.4)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification	COHESIVE SOILS Blows/foot	Consistency	NON-COHESIVE SOILS Blows/foot	Density	Soil Descriptions	Proportion
S	Standard Split Spoon	0 - 1	Very Soft	0 - 4	Very Loose	Capitalized Soil Name	Major Component
SL	Large Spoon (O.D.= 3 in)	2 - 4	Soft	5 - 10	Loose	Lower Case Adjective	35% - 50%
T	Thin Wall Tube	5 - 8	Medium Stiff	11 - 24	Medium Dense	Some	20% - 35%
U	Undisturbed Piston	9 - 15	Stiff	25 - 50	Dense	Little	10% - 20%
O	Open End Rod	16 - 30	Very Stiff	> 50	Very Dense	Trace	1% - 10%
A	Auger Flight	31 - 60	Hard	WOR - Weight of Rod		ENGLISH	
C	Core Barrel	> 60	Very Hard	WOH - Weight of Hammer			
NR	Not Recorded						

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Kanc Site 3 Boring Log

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

New Hampshire DOT

BORING NO.	B27
SHEET NO.	1 OF 1
STA.	OFF.
BASELINE	Stinson Lake Road
ELEVATION (ft)	NR
START/END	12/14/06 / 12/14/06
DRILLER	P. Huckins (NHDOT)
INSPECTOR	Doug Rogers
CLASSIFIER	DRR
EAST/NORTH (ft)	948315/502097

PROJECT NAME **STATEWIDE 14282K** BRIDGE NO. N/A

DESCRIPTION Spring Load Restriction Research

GROUNDWATER

DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE	S	NW	Pavement
SIZE I.D. (in)	1.375	3	6.0
HAMMER WT. (lb)	140		
HAMMER FALL (in)	30		
HAMMER TYPE	Automatic		

DRILL RIG: CME 45 Truck

DEPTH (ft)	STRATUM CHANGE (ft) DEPTH	STRATUM CHANGE (ft) ELEVATION	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0							-PAVEMENT- (0.7' new mix, 0.1' old mix)
	0.8	0.0	5 6 2 2	S1	0.5 [25]	0.8 – 2.8	Loose, dark greyish brown and dark yellowish brown, COARSE-FINE SAND, some-little gravel, slight trace of organics (<5%), occasional piece of asphalt -FILL-
	3.0	0.0	10 11 9 11	S2	0.7 [35]	3.0 – 5.0	Medium dense, greyish brown, FINE SAND, little medium sand, trace fine gravel, trace coarse sand -GLACIAL OUTWASH-
5			8 9 9 9	S3	1.2 [60]	5.0 – 7.0	Greyish brown, FINE SAND, little medium sand, little-trace gravel, little-trace silt, trace coarse sand
	6.0	0.0					Olive-olive grey, FINE SAND, little silt, trace gravel, trace coarse-medium sand -GLACIAL TILL-
			10 8 10 19	S4	1.4 [70]	7.0 – 9.0	Medium dense, light olive brown-olive, FINE SAND, some-little silt, little gravel, little-trace coarse-medium sand
			26 40/0.4	S5	0.6 [67]	9.0 – 9.9	Olive-light olive brown, FINE SAND, some silt, trace gravel, trace coarse-medium sand, refusal at 9.9' w/ split spoon
10							Bottom of Exploration @ 9.9 ft (El. 0.0)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS

Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS

Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

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Stinson Lake Road Boring Log

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

New Hampshire DOT

PROJECT NAME	STATEWIDE 14282K
BRIDGE NO.	N/A
DESCRIPTION	Spring Load Restriction Research

BORING NO.	B24
SHEET NO.	1 OF 1
STA.	
OFF.	
BASELINE	North Groton Road
ELEVATION (ft)	NR
START/END	12/14/06 / 12/14/06
DRILLER	P. Huckins (NHDOT)
INSPECTOR	Doug Rogers
CLASSIFIER	DRR
EAST/NORTH (ft)	933905/454180

GROUNDWATER

DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE:	S	NW	Pavement
SIZE I.D. (in):	1.375	3	6.0
HAMMER WT. (lb):	140	DRILL RIG	
HAMMER FALL (in):	30	CME 45 Truck	
HAMMER TYPE:	Automatic		

DEPTH (ft)	STRATUM CHANGE (ft) DEPTH	STRATUM CHANGE (ft) ELEVATION	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0							-PAVEMENT- (0.35' new mix, 0.35' old mix)
	0.7	0.0	15 5 6 7	S1	1.1 [55]	0.5 - 2.5	Broken-up old mix (pavement) Medium dense, dark brown and dark greyish brown, fine sandy SILT, to olive, SILT, trace gravel, trace coarse sand -FILL-
	3.5	0.0	5 5 12 22	S2	1.2 [60]	2.5 - 4.5	Dark yellowish brown and light olive brown, silty FINE SAND, mixed w/ pieces of asphalt, little gravel, little coarse-medium sand Olive-olive grey, silty FINE SAND, little silt, little-trace gravel, trace coarse-medium sand
5			20 27 33 36	S3	1.4 [70]	4.5 - 6.5	Very dense, olive grey-brownish grey, FINE SAND, some-little silt, little-trace gravel, trace coarse-medium sand -GLACIAL TILL-
			19 27 26 29	S4	1.5 [75]	6.5 - 8.5	Very dense, similar to S3 w/ isolated medium-fine sand layer at 7.5'
10			16 19 31 30	S5	1.4 [70]	8.5 - 10.5	Dense, brownish grey-olive grey, MEDIUM-FINE SAND, some-little gravel, little silt, little coarse sand
							Bottom of Exploration @ 11.0 ft (El. 0.0)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS

Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS

Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

TB-08 S:\GINT\W\PROJECTS\STATEWIDE\14282K\RESEARCH BORINGS B1_B27.GPJ 9/4/2008 11:58:04 AM TB-08

North Groton Road Boring Log

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

New Hampshire DOT

PROJECT NAME STATEWIDE 14282K BRIDGE NO. N/A
DESCRIPTION Spring Load Restriction Research

BORING NO. **B20**
SHEET NO. 1 OF 1
STA. ______ OFF. ______
BASELINE Rumney Patrol Shed
ELEVATION (ft) NR
START/END 12/13/06 / 12/13/06
DRILLER P. Huckins (NHDOT)
INSPECTOR Doug Rogers
CLASSIFIER DRR
EAST/NORTH (ft) 939131/471493

GROUNDWATER

DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE	S	NW	Pavement
SIZE I.D. (in)	1.375	3	6.0
HAMMER WT. (lb)	140	DRILL RIG	
HAMMER FALL (in)	30	CME 45 Truck	
HAMMER TYPE	Automatic		

DEPTH (ft)	STRATUM CHANGE DEPTH (ft)	STRATUM CHANGE ELEVATION (ft)	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0	0.3	0.0					-PAVEMENT-
	0.8	0.0	21, 15, 6, 9	S1	1.2 [60]	0.3 - 2.3	Greyish brown-brownish grey, coarse-fine sandy GRAVEL, trace silt. Medium dense, very dark brownish grey, fine sandy SILT/silty FINE SAND, trace fibers, occasional wood fragment, piece of red brick -FILL-
			3, 2, 3, 3	S2	1.1 [55]	2.5 - 4.5	Loose, dark greyish brown, COARSE-MEDIUM SAND mixed w/ dark brownish grey, fine sandy SILT, over dark yellowish brown, FINE SAND, some silt to "silty"
5	4.5	0.0	12, 12, 13, 13	S3	0.9 [45]	4.5 - 6.5	Dense, dark yellowish brown, medium-fine sandy GRAVEL, little-trace silt -GLACIAL OUTWASH-
			14, 15, 13, 7	S4	0.6 [30]	6.5 - 8.5	Dense, grey-brownish grey, coarse-fine sandy GRAVEL
10			11, 9, 8, 10	S5	0.9 [45]	8.5 - 10.5	Medium dense, grey-brownish grey, FINE SAND, trace medium sand
							Bottom of Exploration @ 10.5 ft (EL 0.0)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

TB-08 S:\GINTW\PROJECTS\STATEWIDE\14282K\RESEARCH BORINGS B1_B27.GPJ 9/4/2008 11:57:59 AM TB-08

Rumney Shed Boring Log

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

PROJECT NAME **STATEWIDE 14282K** BRIDGE NO. N/A
DESCRIPTION Spring Load Restriction Research

BORING NO. **B16**
SHEET NO. 1 OF 1
STA. ____ OFF. ____
BASELINE Warren Patrol Shed
ELEVATION (ft) NR
START/END 12/12/06 / 12/12/06
DRILLER P. Huckins (NHDOT)
INSPECTOR Doug Rogers
CLASSIFIER DRR
EAST/NORTH (ft) 923208/507960

GROUNDWATER					
DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE	S	NW	Pavement
SIZE I.D. (in)	1.375	3	6.0
HAMMER WT. (lb)	140	DRILL RIG	
HAMMER FALL (in)	30	CME 45 Truck	
HAMMER TYPE	Automatic		

DEPTH (ft)	STRATUM CHANGE (ft) DEPTH	STRATUM CHANGE (ft) ELEVATION	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0	0.2	0.0					-PAVEMENT-
			21 29/0.2	S1	0.7 [100]	0.3 - 1.0	Dark yellowish brown, gravelly COARSE-FINE SAND, little silt Note: refusal on cobble at 1.0'; advanced w/ roller bit to 2.0' -FILL-
	2.5	0.0	12 21 33 24	S2	0.8 [40]	2.0 - 4.0	Similar to S1 Very dense, dark yellowish brown and dark greyish brown, coarse-fine sandy GRAVEL, trace silt, cobbles likely
5			17 18 18 35	S3	1.1 [55]	4.0 - 6.0	Dense, dark greyish brown, gravelly COARSE-FINE SAND, trace silt -GLACIAL OUTWASH-
			40 39 37 35	S4	1.2 [60]	6.0 - 8.0	Very dense, brownish grey-greyish brown, medium-fine sandy GRAVEL, some coarse sand, cobles likely
10			20 18 22 27	S5	1.2 [60]	8.0 - 10.0	Dense, greyish brown-brown, coarse-fine sandy GRAVEL, w/ 7" layer of fine sand, trace silt Advanced to 10.5' w/ roller bit
							Bottom of Exploration @ 10.5 ft (El. 0.0)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

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Wentworth (aka Warren) Shed Boring Log

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

New Hampshire DOT

PROJECT NAME **STATEWIDE 14282K** BRIDGE NO. N/A
DESCRIPTION Spring Load Restriction Research

BORING NO. B13
SHEET NO. 1 OF 1
STA. OFF.
BASELINE Lake Tarleton Road
ELEVATION (ft) NR
START/END 12/12/06 / 12/12/06
DRILLER P. Huckins (NHDOT)
INSPECTOR Doug Rogers
CLASSIFIER DRR
EAST/NORTH (ft) 903627/539088

GROUNDWATER					
DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE:	S	NW	Pavement
SIZE I.D. (in):	1.375	3	6.0
HAMMER WT. (lb):	140	DRILL RIG	
HAMMER FALL (in):	30	CME 45 Truck	
HAMMER TYPE:	Automatic		

DEPTH (ft)	STRATUM CHANGE (ft) DEPTH	STRATUM CHANGE (ft) ELEVATION	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0							-PAVEMENT- (0.5' new mix, 0.25' old mix)
	0.8	0.0					
	1.4 1.6 1.9	0.0 0.0 0.0	13 9 5 3	S1	1.3 [65]	1.0 3.0	Dark greyish brown, COARSE-FINE SAND, little gravel, trace silt -coal tar mix- Dark brownish grey, SILT, little-trace organics, trace fine gravel, trace coarse-medium sand -FILL-
			5 2 5 15	S2	0.3 [15]	3.0 5.0	Loose, dark grey and dark greyish brown, COARSE-FINE SAND, some-little silt, trace organics Note: small wood fragments in washwater while advancing to 5.0'
5	5.3	0.0	11 5 7 5	S3	1.0 [50]	5.0 7.0	Similar to S2 Medium dense, dark grey, SILT and silty FINE SAND, little gravel, little coarse-medium sand, little-trace clay -GLACIAL TILL-
			6 6 6 11	S4	1.3 [65]	7.0 9.0	Medium dense, grey-dark grey, SILT, little-trace gravel, trace coarse-medium sand
10			12 13 14 15	S5	1.4 [70]	9.0 11.0	Dense, grey, fine sandy SILT to silty FINE SAND, little-trace medium sand, trace gravel, trace coarse sand
							Bottom of Exploration @ 11.0 ft (El. 0.0) Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS

Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS

Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

TB-08 S:\GINT\W\PROJECTS\STATEWIDE\14282K\RESEARCH BORINGS B1_B27.GPJ 9/4/2008 11:57:48 AM TB-08

Lake Tarleton Boring Log

TEST BORING REPORT

STATE OF NEW HAMPSHIRE DEPARTMENT OF TRANSPORTATION
MATERIALS & RESEARCH BUREAU - GEOTECHNICAL SECTION

PROJECT NAME **STATEWIDE 14282K** BRIDGE NO. N/A
DESCRIPTION Spring Load Restriction Research

BORING NO. **B10**
SHEET NO. 1 OF 1
STA. OFF.
BASELINE Route 25-c (Warren Vil.)
ELEVATION (ft) NR
START/END 12/12/06 / 12/12/06
DRILLER P. Huckins (NHDOT)
INSPECTOR Doug Rogers
CLASSIFIER DRR
EAST/NORTH (ft) 920720/522597

GROUNDWATER					
DATE	TIME	DEPTH (ft)	ELEV. (ft)	BOTTOM OF CASING	BOTTOM OF HOLE
		NR			

EQUIPMENT	SAMPLER	CASING	CORE
TYPE:	S	NW	Pavement
SIZE I.D. (in):	1.375	3	6.0
HAMMER WT. (lb):	140	DRILL RIG	
HAMMER FALL (in):	30	CME 45 Truck	
HAMMER TYPE:	Automatic		

DEPTH (ft)	STRATUM CHANGE (ft) DEPTH	STRATUM CHANGE (ft) ELEVATION	BLOWS PER 0.5 ft	SAMPLE NUMBER	SAMPLER RECOVERY (ft) [%]	DEPTH RANGE (ft)	FIELD CLASSIFICATION AND REMARKS
0							-PAVEMENT-
	0.6	0.0					
	1.5	0.0	7 4 3 7	S1	1.5 [75]	1.0 – 3.0	Black and dark yellowish brown, COARSE-FINE SAND, some-little gravel, some-little silt Loose, olive, SILT (non-cohesive), w/ occasional dark yellowish brown medium sand layer
			8 9 10 11	S2	1.3 [65]	3.0 – 5.0	Medium dense, brownish grey and greyish brown, MEDIUM-FINE SAND, little to trace silt, w/ occasional dark yellowish brown mottle -GLACIAL FLUVIAL-
5			7 10 13 12	S3	1.4 [70]	5.0 – 7.0	Medium dense, brownish grey-grey, MEDIUM-FINE and FINE SANDS, occasional dark yellowish brown medium sand layer
			8 9 12 10	S4	1.3 [65]	7.0 – 9.0	Medium dense, grey-brownish grey, FINE SAND, little silt
10			5 4 4 7	S5	1.4 [70]	9.0 – 11.0	Loose, grey-brownish grey, FINE SAND, trace medium sand, occasional layer dark yellowish brown medium sand
							Bottom of Exploration @ 11.0 ft (El. 0.0)
							Note: Groundwater monitoring well installed, see well log for details
15							
20							
25							

Sampler	Identification
S	Standard Split Spoon
SL	Large Spoon (O.D.= 3 in)
T	Thin Wall Tube
U	Undisturbed Piston
O	Open End Rod
A	Auger Flight
C	Core Barrel
NR	Not Recorded

COHESIVE SOILS Blows/foot	Consistency
0 - 1	Very Soft
2 - 4	Soft
5 - 8	Medium Stiff
9 - 15	Stiff
16 - 30	Very Stiff
31 - 60	Hard
> 60	Very Hard

NON-COHESIVE SOILS Blows/foot	Density
0 - 4	Very Loose
5 - 10	Loose
11 - 24	Medium Dense
25 - 50	Dense
> 50	Very Dense

WOR - Weight of Rod
WOH - Weight of Hammer

Soil Descriptions	Proportion
Capitalized Soil Name	Major Component
Lower Case Adjective	35% - 50%
Some	20% - 35%
Little	10% - 20%
Trace	1% - 10%

ENGLISH

TB-06 S:\GINTW\PROJECTS\STATEWIDE\14282K\RESEARCH BORINGS B1_B27.GPJ 9/4/2008 11:57:43 AM TB-06

Warren Flats Boring Log

Appendix E

HOBO Data Logger Locations

Spring 2007 and Spring 2008 HOBO Subsurface Temperature Data Logger Locations

Test Site	HOBO Serial #	Tube #	Data Logger #	Depth Below Pavement Surface	Plus Or Minus [ ]	Actual Depth Below Pavement Surface
Kanc West (1) *	1104834	1	1	6"	1.5"	7.5"
	1104836	1	2	12"	1.5"	13.5"
	1104846	1	3	18"	1.5"	19.5"
	1104822	1	4	30"	1.5"	31.5"
	1104828	1	5	54"	1.5"	55.5"
	1104829	1	6	78"	1.5"	79.5"
Kanc Middle (2) *	1104874	2	1	6"	1.5”	7”
	1104875	2	2	12"	1.5”	13”
	1104832	2	3	18"	1.5”	19”
	1104840	2	4	30"	1.5”	31”
	1104859	2	5	54"	1.5”	55”
	1104860	2	6	78"	1.5”	79”
Kanc East (3) *	1104841	3	1	6"	0.5"	6.5"
	1104861	3	2	12"	0.5"	12.5"
	1104854	3	3	18"	0.5"	18.5"
	1104868	3	4	30"	0.5"	30.5"
	1104848	3	5	54"	0.5"	54.5"
	1104847	3	6	78"	0.5"	78.5"
Warren Flats **	1104871	4	1	6"	[0.5"]	5.5"
	1104858	4	2	12"	[0.5"]	11.5"
	1104862	4	3	18"	[0.5"]	17.5"
	1104835	4	4	30"	[0.5"]	29.5"
	1104839	4	5	54"	[0.5"]	53.5"
	1104867	4	6	78"	[0.5"]	77.5"
Lake Tarleton **	1104865	5	1	6"	[2.0"]	4"
	1104864	5	2	12"	[2.0"]	10"
	1104853	5	3	18"	[2.0"]	16"
	1104825	5	4	30"	[2.0"]	28"
	1104851	5	5	54"	[2.0"]	52"
	1104850	5	6	78"	[2.0"]	76"
Wentworth Shed (202) **	1104844	6	1	6"	[2.0"]	4"
	1104827	6	2	12"	[2.0"]	10"
	1104849	6	3	18"	[2.0"]	16"
	1104842	6	4	30"	[2.0"]	28"

Spring 2007 and Spring 2008 HOBO Subsurface Temperature Data Logger Locations

Test Site	HOBO Serial #	Tube #	Data Logger #	Depth Below Pavement Surface	Plus Or Minus [ ]	Actual Depth Below Pavement Surface
Wentworth Shed (202) **	1104823	6	5	54"	[2.0"]	52"
	1104838	6	6	78"	[2.0"]	76"
Rumney Shed (203) **	1104845	7	1	6"	[1"]	5"
	1104852	7	2	12"	[1"]	11"
	1104877	7	3	18"	[1"]	17"
	1104869	7	4	30"	[1"]	29"
	1104876	7	5	54"	[1"]	53"
	1104855	7	6	78"	[1"]	77"
North Groton Road **	1104824	8	1	6"	0"	6"
	1104856	8	2	12"	0"	12"
	1104843	8	3	18"	0"	18"
	1104826	8	4	30"	0"	30"
	1104831	8	5	54"	0"	54"
	1104872	8	6	78"	0"	78"
Stinson Lake Road **	1104857	9	1	6"	0.5"	6.5"
	1104837	9	2	12"	0.5"	12.5"
	1104863	9	3	18"	0.5"	18.5"
	1104866	9	4	30"	0.5"	30.5"
	1104873	9	5	54"	0.5"	54.5"
	1104830	9	6	78"	0.5"	78.5"

NOTES: * As of 5/5/08
** As of 5/7/08

2009 Spring HOBO Subsurface Temperature Data Logger Locations (note some HOBOs have been relocated from 2008 to 2009)

Test Site	HOBO Serial #	Tube #	Data Logger #	Depth Below Pavement Surface	Plus Or Minus [ ]	Actual Depth Below Pavement Surface
Kanc West (1) *	1104834	1	1	6"	1.5"	7.5"
	1104836	1	2	12"	1.5"	13.5"
	1104846	1	3	18"	1.5"	19.5"
	1104822	1	4	24"	1.5"	25.5"
	1104828	1	5	30"	1.5"	31.5"
	1104829	1	6	36"	1.5"	37.5"
Added 12/2/2008	2262471	1	7	42"	1.5	43.5"
Added 12/2/2008	2262470	1	8	54"	1.5	55.5"
Added 12/2/2008	2262469	1	9	78"	1.5	79.5"
Kanc Middle (2) *	1104874	2	1	6"	1"	7"
	1104875	2	2	12"	1"	13"
	1104832	2	3	18"	1"	19"
	1104840	2	4	24"	1"	25"
	1104859	2	5	30"	1"	31"
	1104860	2	6	36"	1"	37"
Added 12/2/2008	2262474	2	7	42"	1"	43"
Added 12/2/2008	2262473	2	8	54"	1"	55"
Added 12/2/2008	2262472	2	9	78"	1"	79"
Kanc East (3) *	1104841	3	1	6"	0.75"	6.75"
	1104861	3	2	12"	0.75"	12.75"
	1104854	3	3	18"	0.75"	18.75"
	1104868	3	4	24"	0.75"	24.75"
	1104848	3	5	30"	0.75"	30.75"
	1104847	3	6	36"	0.75"	36.75"
Added 12/2/2008	2262475	3	7	42"	0.75"	42.75"
Added 12/2/2008	2262476	3	8	54"	0.75"	54.75"
Added 12/2/2008	2262477	3	9	78"	0.75"	78.75"
Warren Flats **	1104871	4	1	6"	[0.5"]	5.5"
	1104858	4	2	12"	[0.5"]	11.5"
	1104862	4	3	18"	[0.5"]	17.5"
	1104835	4	4	24"	[0.5"]	23.5"
	1104839	4	5	30"	[0.5"]	29.5"
	1104867	4	6	36"	[0.5"]	35.5"
Added 12/4/2008	2254697	4	7	42"	[0.5"]	41.5"
Added 12/4/2008	2254696	4	8	54"	[0.5"]	53.5"
Added 12/4/2008	2254695	4	9	78"	[0.5"]	77.5"

2009 Spring HOBO Subsurface Temperature Data Logger Locations (note some HOBOs have been relocated from 2008 to 2009)

Test Site	HOBO Serial #	Tube #	Data Logger #	Depth Below Pavement Surface	Plus Or Minus [ ]	Actual Depth Below Pavement Surface
Lake Tarleton **	1104865	5	1	6"	[1.0"]	5"
	1104864	5	2	12"	[1.0"]	11"
	1104853	5	3	18"	[1.0"]	17"
	1104825	5	4	24"	[1.0"]	23"
	1104851	5	5	30"	[1.0"]	29"
	1104850	5	6	36"	[1.0"]	35"
Added 12/4/2008	2254694	5	7	42"	[1.0"]	41"
Added 12/4/2008	2254693	5	8	54"	[1.0"]	53"
Added 12/4/2008	2254692	5	9	78"	[1.0"]	77"
Wentworth Shed (202) **	1104844	6	1	6"	[2.0"]	4"
	1104827	6	2	12"	[2.0"]	10"
	1104849	6	3	18"	[2.0"]	16"
	1104842	6	4	24"	[2.0"]	22"
	1104823	6	5	30"	[2.0"]	28"
	1104838	6	6	36"	[2.0"]	34"
Added 12/5/2008	2254687	6	7	42"	[2.0"]	40"
Added 12/5/2008	2254686	6	8	54"	[2.0"]	52"
Added 12/5/2008	2254685	6	9	78"	[2.0"]	76"
Rumney Shed (203) **	1104845	7	1	6"	[1.5"]	4.5"
	1104852	7	2	12"	[1.5"]	10.5"
	1104877	7	3	18"	[1.5"]	16.5"
	1104869	7	4	24"	[1.5"]	22.5"
	1104876	7	5	30"	[1.5"]	28.5"
	1104855	7	6	36"	[1.5"]	34.5"
Added 12/1/2008	2254698	7	7	42"	[1.5"]	40.5"
Added 12/1/2008	2254699	7	8	54"	[1.5"]	52.5"
Added 12/1/2008	2254700	7	9	78"	[1.5"]	76.5"
North Groton Road **	1104824	8	1	6"	[0.5"]	5.5"
	1104856	8	2	12"	[0.5"]	11.5"
	1104843	8	3	18"	[0.5"]	17.5"
	1104826	8	4	24"	[0.5"]	23.5"
	1104831	8	5	30"	[0.5"]	29.5"
	1104872	8	6	36"	[0.5"]	35.5"
Added 12/4/2008	2254701	8	7	42"	[0.5"]	41.5"
Added 12/4/2008	2254688	8	8	54"	[0.5"]	53.5"

2009 Spring HOBO Subsurface Temperature Data Logger Locations (note some HOBOs have been relocated from 2008 to 2009)

Test Site	HOBO Serial #	Tube #	Data Logger #	Depth Below Pavement Surface	Plus Or Minus [ ]	Actual Depth Below Pavement Surface
Added 12/4/2008	2262468	8	9	78"	[0.5"]	77.5"

Stinson Lake Road **	1104857	9	1	6"	[1.0"]	5"
	1104837	9	2	12"	[1.0"]	11"
	1104863	9	3	18"	[1.0"]	17"
	1104866	9	4	24"	[1.0"]	23"
Stinson Lake Road **	1104873	9	5	30"	[1.0"]	29"
	1104830	9	6	36"	[1.0"]	35"
Added 12/1/2008	2254689	9	7	42"	[1.0"]	41"
Added 12/1/2008	2254690	9	8	54"	[1.0"]	53"
Added 12/1/2008	2254691	9	9	78"	[1.0"]	77"

NOTES: * As of 5/5/08

** As of 5/7/08