Review of Current Asphalt Cement Performance Grade

Temperature Requirements in the Maritime Provinces

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Abstract

Performance Graded Asphalt Binders (PGAB) are selected under the Superpave system to provide superior performance according to the climate in which the pavement will serve. Rutting and fatigue resistance are provided at selected reliability levels by meeting various physical properties at corresponding site-specific high and low design pavement temperatures. These design temperatures have been previously determined using climatic data from across North America within the LTPPBind V3.1 software, and more recently can be assessed using LTPPBind Online. The high and low design pavement temperature and performance grades were determined using three approaches: LTPPBind Online; LTPPBind V3.1 model with climate data captured through the Road Weather Information Systems (RWIS) network utilized by the Maritime Provinces; and, using direct measurements of pavement temperature obtained using the RWIS network. Differences in the results were compared to assess possible changes arising from climate change effects and to update pavement temperatures required for asphalt binder testing under AASHTO M332 ("Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test") specification. LTPPBind Online was discontinued in the study due to differences observed in computing certain climate statistics compared to LTPPBind V3.1 and hand calculations based on the reported equations contained within both versions of the software. An average increase in the calculated high temperature grade requirement of 2.89˚C was observed between results based on RWIS air temperature data versus approximately 25 years of Environment Canada climate data used within LTPPBind V3.1. However, a linear bias was observed when comparing the RWIS air temperature and LTPPBind V3.1 results which may have influenced the outcome. Pavement design temperatures developed using direct measurements at the RWIS stations were found to exhibit similar spatial variations to those developed using LTPPBind 3.1, but appeared to exhibit slight increases in both the high and low design temperatures over time of 0.2 ˚C and 3.28 ˚C, respectively. It is unknown if these differences are due to climate change effects or differences between the LTTPBind predictive model and direct temperature measurements. Design pavement temperatures should be evaluated annually using a shorter 10-year window of climate data to monitor the rate of change and predictions of future performance grade requirements.

Introduction

Collectively, the Provinces of Nova Scotia, New Brunswick, and Prince Edward Island developed an updated specification for Performance Graded Asphalt Binder (PGAB) in 2018. The new specification is based on AASHTO M332, "Standard Specification for Performance-Graded Asphalt Binder Using Multiple Stress Creep Recovery (MSCR) Test", which involves determining the non-recoverable creep compliance, J_{nr}, at a shear stress of 3.2 kPa using a Dynamic Shear Rheometer (DSR). The MSCR test utilizes the same DSR equipment and asphalt binder sample used in the AASHTO M320 ("Standard Specification for Performance Graded Asphalt Binder") specification but imparts a shear stress on the sample for 1 second, followed by a rest period of 9 seconds. Unlike AASHTO M320 where the test temperature required to meet a certain physical requirement is determined and performance grades are "bumped" to meet traffic loading requirements, a maximum J_{nr} value is specified in AASHTO M332 at the high design pavement temperature for varying traffic grade designations.

The non-recoverable creep compliance, J_{nr}, is determined as the amount of residual strain left in the specimen after repeated creep and recovery, relative to the amount of shear stress that is applied. J_{nr} is defined as the unrecovered shear stress, or the difference between the shear strain measured at the end of the rest period and the initial strain in the sample at the start of the loading cycle, divided by the applied shear stress. The percent recovery provides a measure of the elastic response of the binder and is determined as the amount of strain that is recovered in each cycle, defined as the ratio between the shear strain measured at the end of the rest period and the peak instantaneous shear strain, multiplied by 100%. The responses of polymer modified binders when tested by MSCR at the 3.2 kPa stress level extends into the non-linear viscoelastic range, better representing loading conditions in the pavement and more accurately representing the stiffening and elastic effects of polymer modified binders to resist rutting.

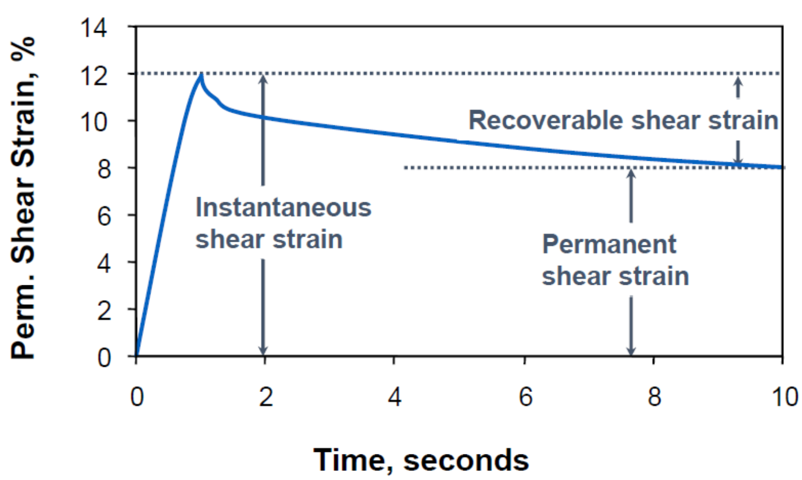

Figure 1. Schematic of MSCR data (from Anderson, 2014).

The differential creep compliance is determined as the percentage increase in J_{nr} when the shear stress is increased from 0.1 kPa to 3.2 kPa. This differential creep compliance is used to check the stress sensitivity of a polymer modified binder. Figure 1 depicts a schematic of MSCR data with the peak instantaneous shear strain and the recoverable and non-recoverable components.

Rationale for Updated Specification

The previous version of the PGAB specifications used throughout the Maritimes was based on AASHTO M320. The critical performance-based characteristics of a binder are measured using a Dynamic Shear Rheometer (DSR) are conducted at high and intermediate pavement service temperatures on binder residues after conditioning in the Rolling Thin Film Oven (RTFO) and Pressure Aging Vessel (PAV), respectively. The measured parameters consist of the complex shear modulus, G*, and the phase angle, δ. The complex shear modulus is the total resistance of the binder to deformation under repeated shear. Since asphalt binders are generally viscoelastic, the complex shear modulus is a vector consisting of an elastic component, G', called the storage modulus, and a viscous component, G", called the loss modulus. The phase angle is defined as the direction of the G* vector with respect to the elastic portion G', as shown in Figure 2.

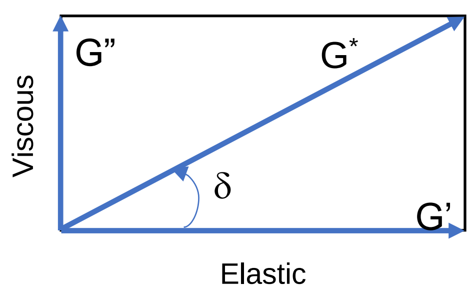

Figure 2 - Schematic of complex shear modulus, G*, and phase angle, δ.

When δ is very small, the shear response of the binder is primarily elastic, and the corresponding strain is recoverable. Conversely, when δ is large, the response is primarily viscous, and the corresponding strain is non-recoverable.

DSR testing is conducted on the original binder and RTFO residue at the high PG temperature to evaluate the ability of the binder to resist rutting, while DSR testing is conducted on the PAV residue at the intermediate temperature to evaluate the ability of the binder to resist fatigue cracking.

Rutting is a permanent deformation of the pavement structure that occurs due to movement of the materials under repeated loads. This movement may occur within bound hot mix asphalt concrete layers or within the underlying granular base and is typically the result of consolidation or plastic flow. In addition to using larger sized well-graded aggregate with rough texture and angular shape, and adequate compaction during construction, a high complex modulus, G*, and low phase angle, δ, will improve the resistance of a hot mix asphalt mixture to rutting by providing high stiffness and elasticity in the material. Equation 1 illustrates that for stress-controlled rutting under cyclic loading, the amount of work dissipated, W_c, under a cyclic stress σ_o, is reduced for higher values of G* and lower values of δ. The increased shear modulus reduces the overall amount of deformation and the increased elasticity of the binder increases the proportion of that deformation which is recoverable (non-permanent).

$$W_c = \pi\sigma_o^2/\left(G^*/\sin\delta\right) \qquad \text{Equation 1}$$

Fatigue cracking tends to be more prevalent in thin HMA pavements where it is a strain-controlled phenomenon. Equation 2 indicates that the work dissipated, W_c, under cyclic repetition of a constant strain level, ε_o, is reduced when both G* and δ are reduced. Lower stiffness allows the HMA to deform without building up large stresses and increased elasticity allows a higher proportion of the deformation to be recovered without permanent strain or energy dissipation through heat, plastic flow, crack formation, or crack propagation. All these different methods of energy dissipation contribute to pavement distress.

$$W_c = \pi\varepsilon_o^2\left(G^*\sin\delta\right) \qquad \text{Equation 2}$$

Review of these parameters indicates that increased binder elasticity is beneficial to both rutting and fatigue resistance. Based on Equations 1 and 2, grade bumping to meet elevated traffic loading requirements by using a higher complex shear modulus without increasing elasticity would tend to benefit rutting at the detriment of fatigue performance. Increased amounts of well distributed elastic polymer to meet higher traffic requirements would benefit both rutting and fatigue performance.

The G*/sinδ parameter provided the basis in which AASHTO M320 attempted to ensure adequate resistance to rutting. Poor correlations have been reported between G*/sinδ and the rutting performance of full-scale pavement test sections constructed using different neat, air-blown, Styrene-Butadiene-Styrene (SBS) modified, crumb rubber modified, and Elvaloy modified asphalt binders and subjected to accelerated loading. The coefficient of determination, R^2, was found to be 0.13, indicating that the G*/sinδ variable was a poor predictor of the total amount of rutting that occurred (D'Angelo, 2014). Conversely, the J_{nr} value determined from MSCR testing conducted on the asphalt binders at 64 °C was found to correlate very well with the observed amount of rutting, exhibiting a coefficient of determination, $R^2 = 0.82$. This study clearly presented the improved ability to predict rutting behaviour using the J_{nr} value from MSCR testing compared to the G*/sinδ value used in AASHTO M320.

AASHTO M332 also states that the specifying agency may require compliance with Appendix X1 to ensure that the asphalt binder exhibits elastic response. Appendix X1 presents criteria for the percentage of elastic strain recovery as a function of creep compliance to determine the presence of elastic response and the stress dependence of polymer modified and unmodified asphalt binders. The Maritime Provinces collectively decided that the highest minimum percent recovery value within each traffic grade designation would be required to provide a simple means of ensuring adequate levels of elastic response to the benefit of both fatigue and rutting resistance.

Current concerns regarding possible impacts of global warming, the temperature sensitivity of MSCR test results, and the expectations of improved predictability in pavement performance through the implementation of the MSCR based PGAB specification provided the rationale for re-evaluating the high and low pavement service design temperatures used in specifying PGAB throughout the Maritime Provinces. A PG 58-28 asphalt binder has generally and conservatively been specified in the region as the baseline performance grade, based on initial review of the US Federal Highway Administration LTPPBind software in the mid 1990's.

LTPPBind Online Software

The LTPPBind software was developed to allow highway agencies to select performance grades based on actual temperature conditions at a project site and at the level of designated risk. The software provides a means to estimate high and low pavement service temperatures based on air temperature statistics and latitude for a geographic location. LTPPBind V3.1 included high-temperature asphalt binder selection procedures based on pavement damage concepts.

The current version of the software is LTTPBind Online, which incorporates a novel climate database developed from the new Modern-Era Retrospective Analysis for Research and Applications (MERRA) climatic database which has been collected globally since 1979. The MERRA database provides continuous hourly weather data starting in 1980 on a relatively fine-grained uniform grid at a 0.5-degree latitude by 0.67-degree longitude spatial resolution over the entire globe. The MERRA-2 dataset was introduced in July 2017 because of advances in the data assimilation system that now include hyperspectral radiance and microwave observations. The latitude width of the grid cell was reduced to 0.625 degrees. It was expected that this new database would provide updated PGAB requirements for the Maritimes that would reflect possible climate change and global warming trends.

An initial study of select locations throughout Nova Scotia using LTPPBind Online with the MERRA database indicated that differences in design pavement temperatures appeared to have occurred relative to prior results obtained using LTTPBind V3.1. These results were indicating a possible increase in the pavement design high temperature grade requirement of approximately 6 ˚C, or a full performance grade. However, after several locations analyzed in New Brunswick were found to have unrealistic low temperature statistics, the LTPPBind Online results were deemed questionable. For example, the average lowest yearly air temperature reported by LTPPBind Online for Saint John, New Brunswick, was -38.70 ˚C with a standard deviation of 3.90 ˚C while incorrectly reporting calculated pavement design low temperatures of -28.95 ˚C at 50% reliability and -36.20 ˚C at 98% reliability. These calculated values do not correspond to the reported statistics and reliabilities. Environment Canada climate data listed for the weather station located at the Saint John airport in LTPPBind V3.1 indicated that the mean lowest yearly air temperature was -28.0 ˚C with a standard deviation of 2.5 ˚C.

Further detailed analysis was conducted in August 2018 in which the pavement design low and high temperatures reported in the LTTPBind Online manual were hand calculated and compared to results obtained in LTTPBind V3.1 and LTPPBind Online using the same inputs. It was determined that the 98th percentile pavement design high temperature was being computed differently in LTTPBind Online and the analysis method was dropped from this study.

Road Weather Information Systems Air Temperature Data

The Maritime Provinces have developed a Road Weather Information System (RWIS) system for providing real time weather data in support of highway maintenance activities. These systems include calibrated air and pavement surface temperature sensors which are accurate to 0.1 ˚C and are measured and recorded on a 30 minutes time interval. The calibrations of the air temperature sensors are verified annually using a reference standard instrument. This site-specific RWIS data provides a more robust and current database from which the inputs to the LTTPBind predictive models were determined. Air temperature data from a total of 79 RWIS stations were evaluated throughout the Maritimes, consisting of 47 sites in Nova Scotia, 27 sites in New Brunswick, and 5 sites in Prince Edward Island. Most of these RWIS stations have been in service for 5 to 12 years. This approach based on air temperature measurements was evaluated to maintain consistency of the results with prior utilization of LTPPBind V3.1 and to assess the potential impact of any recent changes to the Maritime climate.

The average and standard deviation of each calendar daily temperature was determined for the full extent of data recorded at each RWIS station. These occurrences would tend to result in a zero-volt sensor output, corresponding to the -40 ˚C minimum measurement range of the calibrated sensor. Data falling outside the 99.5th percentile range for each calendar day were assumed to be erroneous measurements and were filtered out of the database analysis. The remaining data were analyzed to determine the average and standard deviation of the maximum annual 7-day peak daily air temperature and average annual minimum air temperatures.

Pavement design high and low service temperatures were calculated at the 98th percentile value for an allowable rut depth of 10 mm using the LTPPBind predictive equations and the air temperature statistics derived from the RWIS database. These results indicated an average increase in pavement design high temperature throughout the Maritimes over approximately 20 years of 2.89 ˚C compared to the older climate database within LTPPBind V3.1. These results appear to be consistent with a basic assumption that climate change resulting from global warming should increase pavement design high temperatures over time. However, the opposite effect was observed with respect to the pavement design low temperature, which increased by 2.17 ˚C on average throughout the Maritimes. The notion that global warming might result in upward shifts in both high and low design temperatures may be too simplistic. Another possibility may be that the effects of climate change are complex and temperature extremes may shift in opposite directions.

Average annual maximum 7-day peak temperature and average annual minimum air temperatures determined from the 12 RWIS sites geographically spread throughout Nova Scotia were plotted versus similar statistics as determined from LTTPBind V3.1 as shown in Figure 3. A bias can be observed in these results which suggests that the difference between the two data sets is a linearly related to the temperature itself. It is more likely that there is a difference in the method of measurement between these data sets which encompass two different periods of time than the possibility that climate change effects are a strongly linear function of temperature. It is also unlikely that the filtering approach employed to remove randomly occurring erroneous data in the RWIS database would result in a linear correlation over the measurement range.

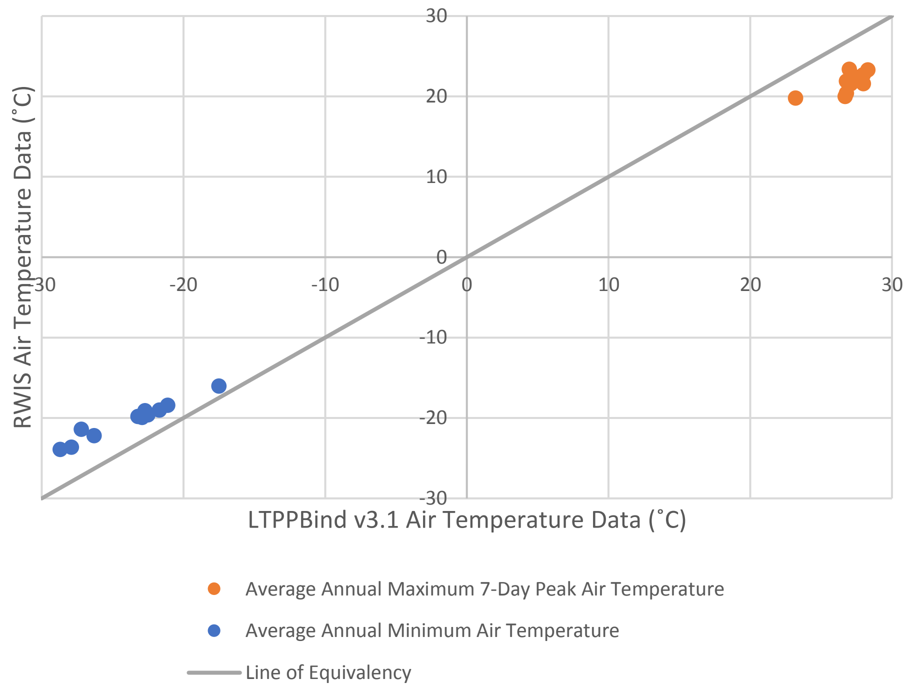

Figure 3. Average design temperatures developed using RWIS air temperatures vs. LTPPBind V3.1.

The LTTPBind predictive model using the RWIS air temperature statistics was considered unreliable for PGAB selection purposes due to the observed bias which is likely to have influenced the results.

Figure 4 provides a plot of the standard deviations for the high and low pavement design temperatures determined using the RWIS air temperature data and those obtained from the LTPPBind V3.1. The standard deviations appear to be generally equivalent and increase in variability with magnitude. This equivalency indicates that despite the shorter duration of the RWIS database with an average timespan of approximately 11 years, it provides similar levels of variability to the LTPPBind database which had an average timespan of 25 years.

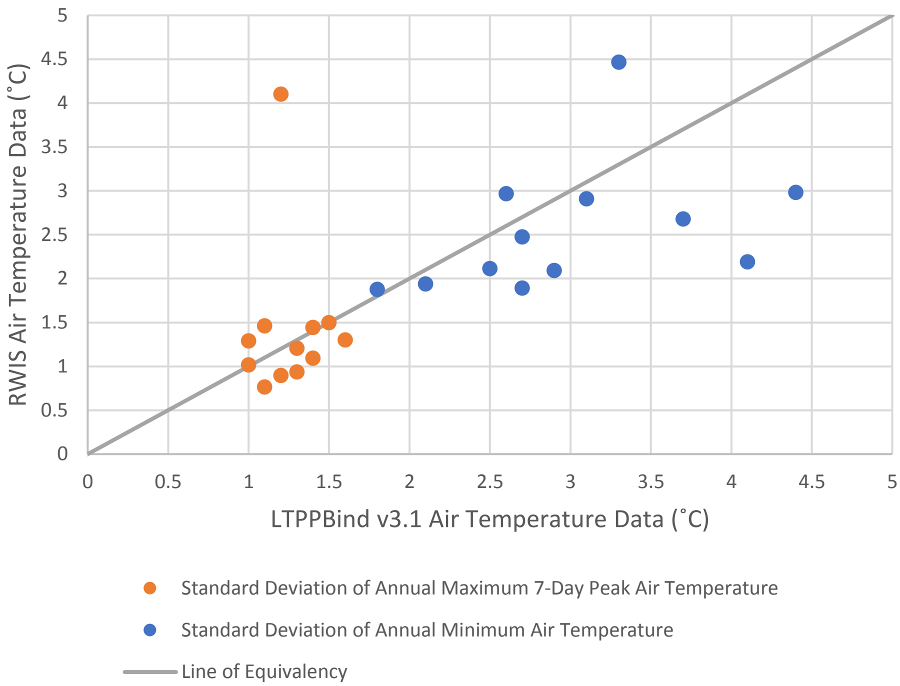

Figure 4. Standard deviations of design temperatures developed using RWIS air temperatures vs. LTPPBind V3.1.

Road Weather Information Systems (RWIS) Pavement Temperature Data

The LTTPBind methodology was developed to provide a means for highway agencies to select asphalt binder performance grades using widely available air temperature data instead of what were relatively sparse instrumented pavement sites available prior to the more recent development of robust RWIS networks. Furthermore, the LTTPBind approach uses the air temperature data to predict pavement temperatures while the actual pavement temperatures are recorded at RWIS stations. The RWIS instrumentation includes specialized pavement surface temperature sensors which record the asphalt concrete temperature at a depth of 3 mm at 30 minutes intervals.

Pavement design high temperatures are estimated at a reference depth of 20 mm below the pavement surface by convention in LTPPBind. A method for estimating the temperature profile with depth through asphalt concrete during the hottest 7-day period of the year was reported in SHRP-A-648A. This model was used to estimate the pavement temperature at the 20 mm reference depth from the annual maximum 7-day peak temperature measured at a depth of 3 mm in the asphalt concrete, and at the surface of the asphalt concrete based on the annual minimum temperature measured at a depth of 3 mm in the asphalt concrete. These temperatures were used to calculate the 98th percentile high and low pavement design temperatures for each RWIS site. Figure 5 shows a contour plot of the variation in the calculated 98th percentile pavement design high temperature over a map of the Maritime Provinces based on the RWIS direct measurement of pavement temperature data, while Figure 6 shows a similar plot of the same statistics obtained using LTPPBind V3.1.

Review of these results indicates that both datasets exhibit very similar spatial variations, but the current high temperature results obtained from the RWIS data appear to have increased more in certain areas within the region, exhibiting a 0.2 ˚C increase on average. Figures 7 and 8 show similar comparisons between the RWIS and LTPPBind V3.1 pavement design low temperatures and indicate an average warming trend of 3.28 ˚C over the approximate 20-year difference between the two datasets.

It must be noted that the LTTPBind results are only estimates of the actual pavement temperatures and the observed differences may be the result of model errors. The errors associated with the depth correction of the measured pavement temperatures are expected to be small, but would be consistent between both results and are independent of the time interval between the datasets.

The RWIS pavement temperature approach to determining design temperatures can provide a consistent approach by which the potential effects of global warming may be monitored over time. Since the average timespan of the RWIS air temperature database provided similar variability to the average 25-year timespan of the LTPPBind V3.1 database, it can be expected that a 10-year window of RWIS pavement temperature data should provide similar levels of reliability. Analyzing the increase and rate of increase in pavement design high and low temperatures using a sliding 10-year window could provide valuable insight regarding climate change and its expected future impact on performance graded asphalt binder requirements. If these design temperatures are indeed increasing, this approach could determine and estimate the rate of increase and its acceleration over time.

Figures 9 and 10 show the similar plots of the high and low pavement design temperature performance grades required in the Maritime Provinces, as determined from the RWIS pavement temperatures and contoured according to the established performance grade intervals established in both the AASHTO M320 and M332 specifications. These results confirm that the PG 58-28 base grade specified under AASHTO M320 for standard traffic loading in most hot mix asphalt pavements in the Maritimes continues to be appropriate throughout most of the region. The exception to this appears to be an area in New Brunswick that is generally northwest of a line connecting Florenceville and Bathurst. A base grade under of PG 58-34 is recommended under standard traffic loading in this area for AASHTO M320 specifications. These results indicate that MSCR tests should currently be conducted at a test temperature of 58 ˚C for applications throughout the Maritime Provinces. However, based on the comparison between the RWIS pavement temperature and LTTPBind V3.1 results, an increased high temperature grade may be required within the next 20-30 years. Ongoing monitoring of the pavement design temperatures using a sliding 10-year window of RWIS pavement temperature data should help determine when this change will be necessary.

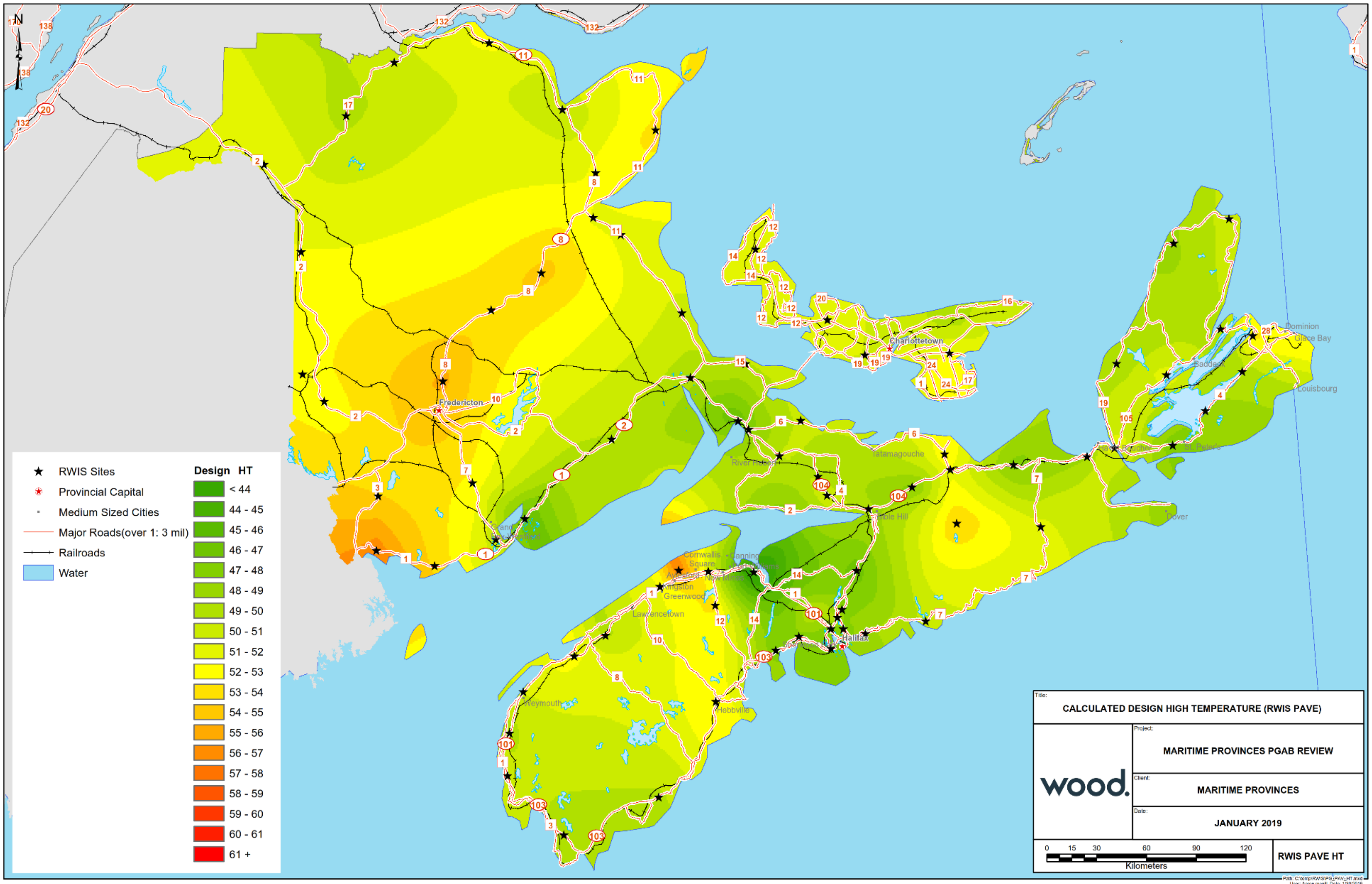

Figure 5. Pavement design high temperatures in the Maritimes (RWIS pavement temperature).

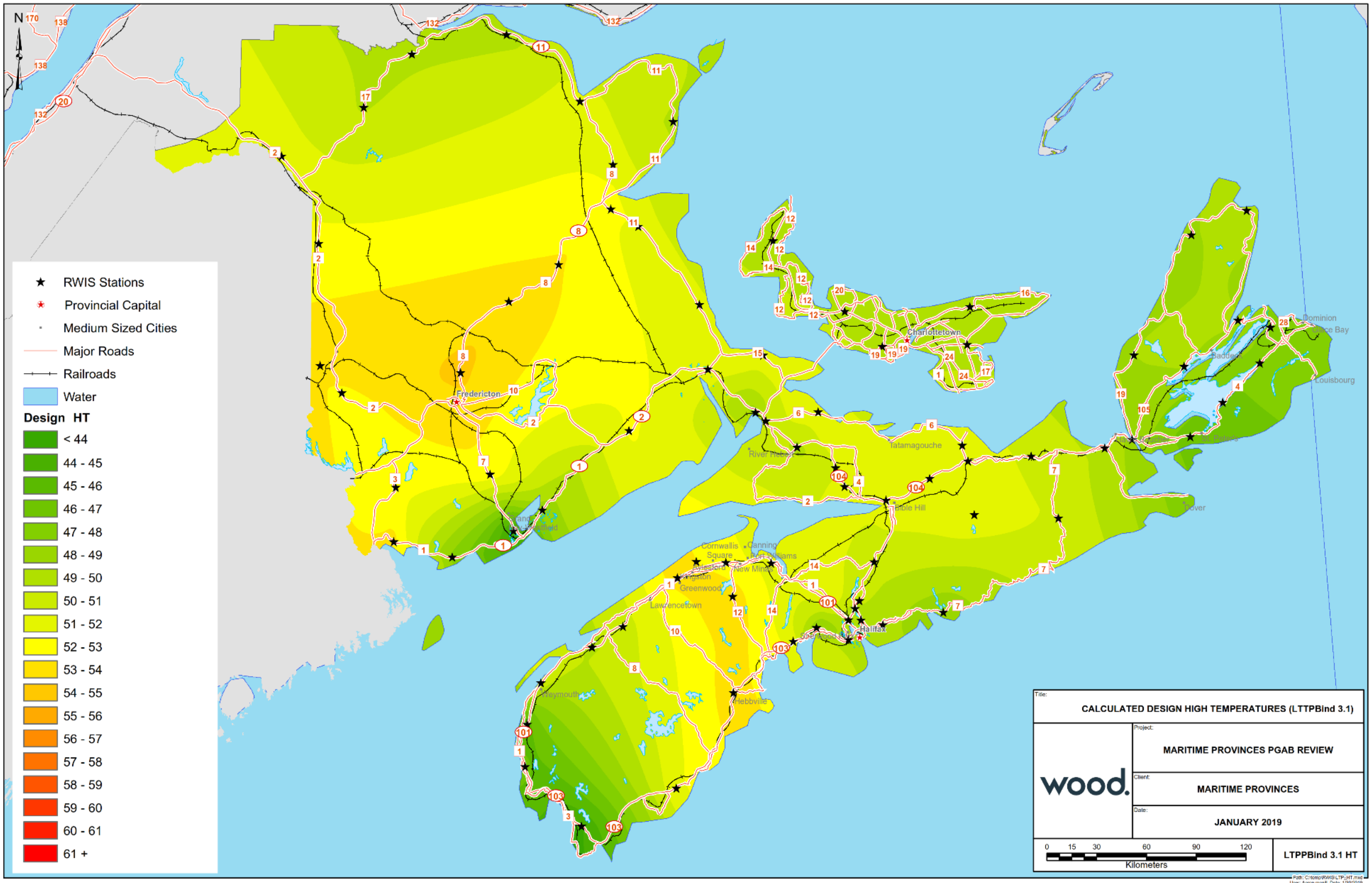

Figure 6. Pavement design high temperatures in the Maritimes (LTPPBind V3.1).

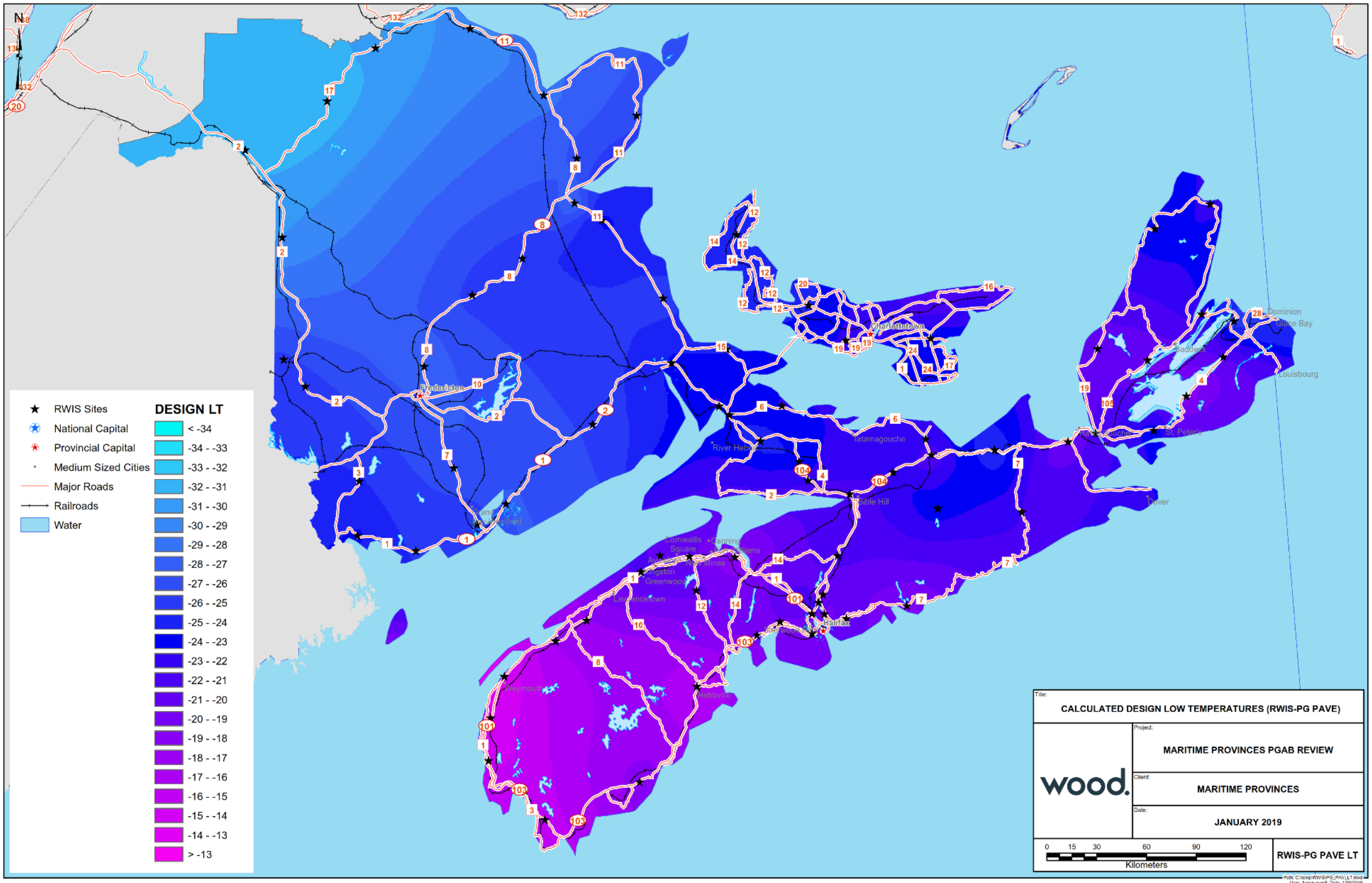

Figure 7. Pavement design low temperatures in the Maritimes (RWIS pavement temperature).

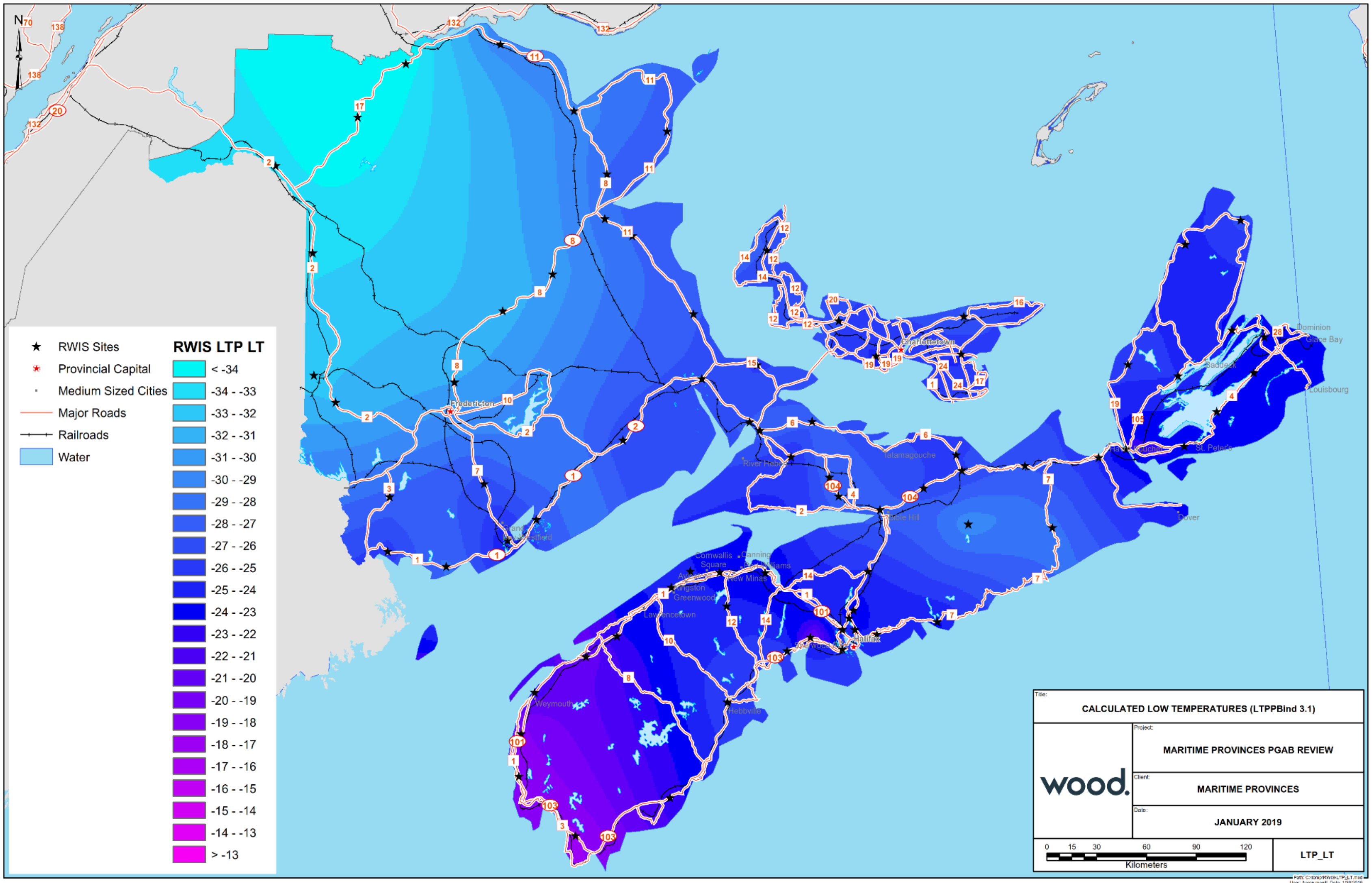

Figure 8. Pavement design low temperatures in the Maritimes (LTPPBind V3.1).

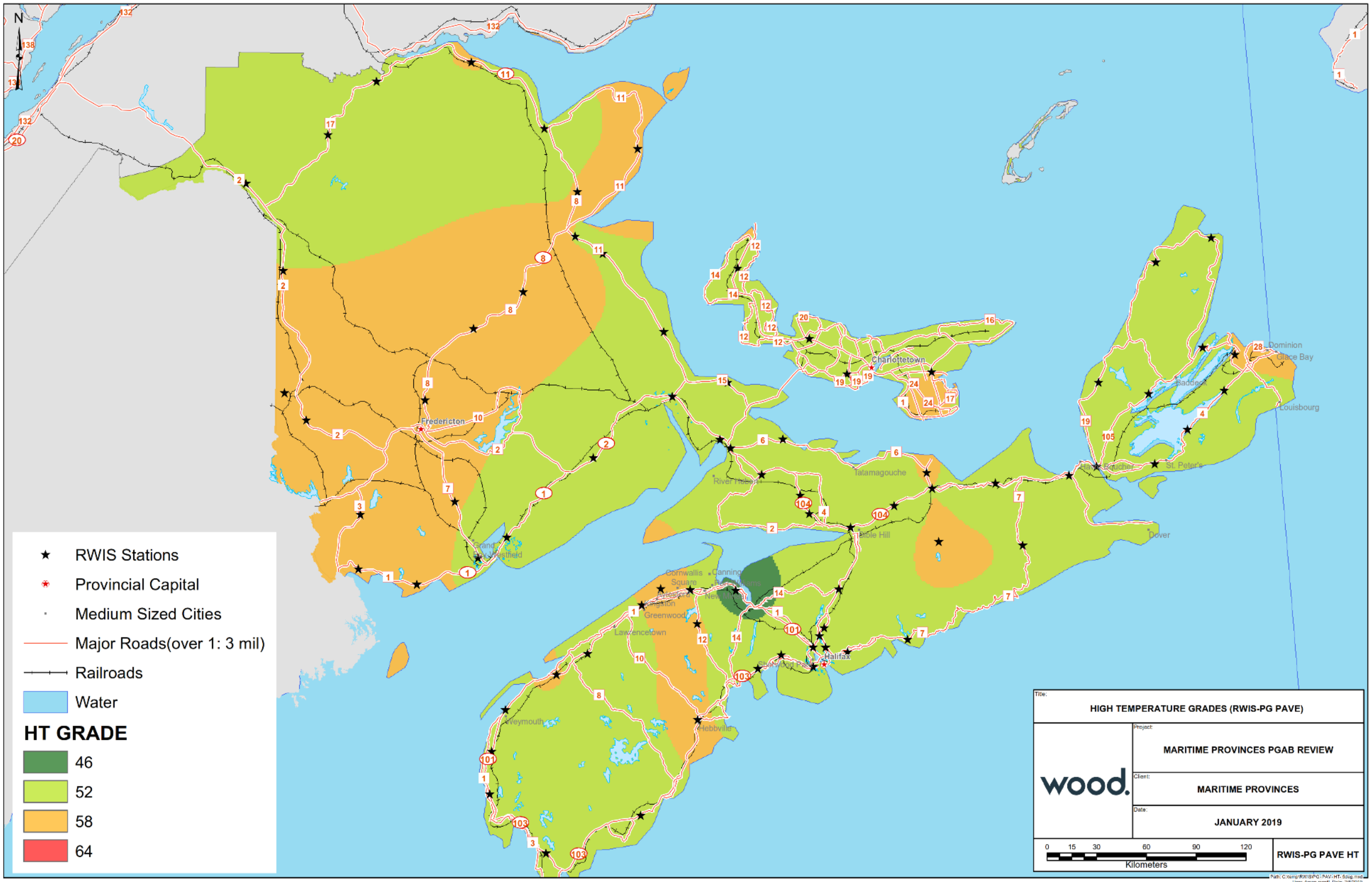

Figure 9. Minimum high temperature performance grades required in the Maritimes (RWIS pavement temperature).

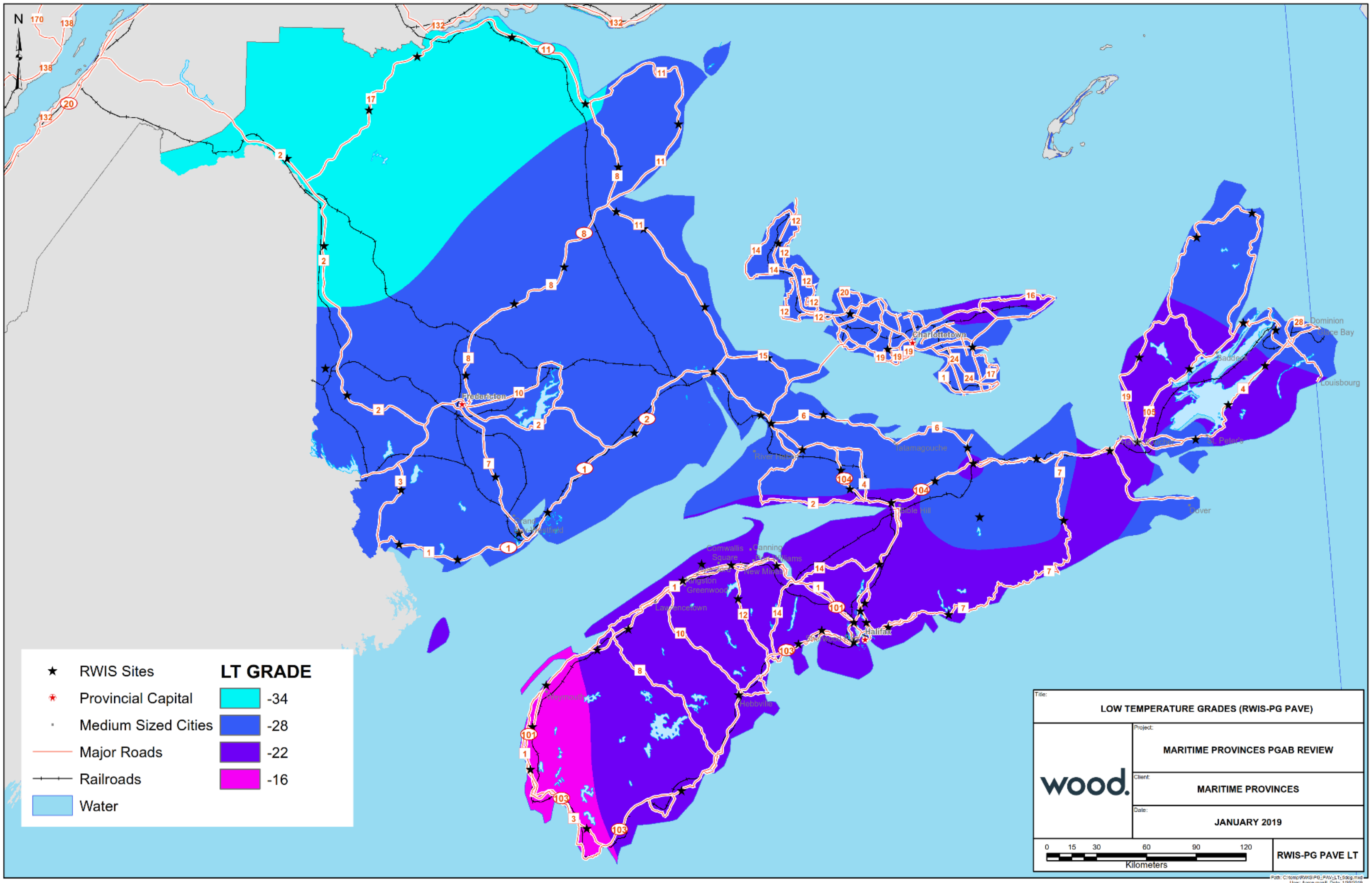

Figure 10. Maximum low temperature performance grades required in the Maritimes (RWIS pavement temperature).

Conclusions

The Maritime Provinces recently updated their performance graded asphalt binder specifications to conform with AASHTO M332, relying on the non-recoverable creep compliance and percent recovery as determined from the MSCR test to evaluate the expected performance of asphalt binders. The MSCR test is performed on RTFO residues at the design high temperature of the pavement for the project location. The range of pavement design temperatures throughout the Maritime Provinces was evaluated using three approaches: the new LTTPBind Online software using the MERRA database; the LTPPBind equations using air temperature statistics measured at RWIS stations throughout the Maritimes; and, by direct measurements of pavement temperatures obtained at the RWIS stations that were adjusted to standardized measurement depths in asphalt pavements. Analyses using both LTPPBind V3.1 and hand calculations based on the reported equations in both versions of the software yielded identical results. The LTPPBind Online software was found to report results that were inconsistent with LTPPBind V3.1 and the hand calculations. Review of pavement design temperatures determined using the RWIS air temperature database versus those reported using LTPPBind V3.1 indicated a linear bias as a function of temperature. Comparison of the design temperature standard deviations developed using the RWIS air temperature database having an average 11-year timespan and using LTPPBind V3.1 database having an average 25-year timespan indicated that the RWIS results provided similar variability. Pavement design temperatures developed using direct measurements at the RWIS stations were found to exhibit similar spatial variations to those developed using LTPPBind 3.1, but appeared to exhibit slight increases in both the high and low design temperatures over time of 0.2 ˚C and 3.28 ˚C, respectively. It is unknown if these differences are due to climate change effects or differences between the LTTPBind predictive model and direct temperature measurements. It is recommended that calculated design temperatures based on a 10-year window of RWIS direct pavement temperature measurements are monitored over time to evaluate the existence and rate of change in PGAB requirements due to possible climate change effects. The results of this study confirmed that a high temperature performance grade of 58 ˚C remains appropriate for the Maritime Provinces region. Similarly, a low temperature grade of -28 ˚C is generally required in the region, except for northwestern New Brunswick where -34 ˚C is required.

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