Cross Slope and Climate Change:
Implications for Highway Design and Road Safety

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Abstract

This paper explores whether there should be consideration for the adoption of increased cross slope on roadway travel lanes to better accommodate climate change impacts such as rainfall intensity, duration, and frequency. The current national guideline of providing a cross slope of 0.02 m/m on paved tangent roadways to provide positive drainage is contrasted against international best practices. An increased cross slope and the associated possible impacts on hydroplaning are discussed. It is shown that by increasing the cross slope from 0.02 to 0.03m/m, water will drain from the travel lanes approximately 23% faster. The province of New Brunswick adopted a stronger 0.03m/m cross slope policy in the early 1990s and their experience to date is summarized. There is a dichotomy that exists between an increased need for better drainage on high-speed facilities and the concern for truck instability that might be associated with crossing the crown of the road. The use of higher cross slopes in many other countries has not led to reports of vehicle instability. This paper argues that the benefits of improved drainage in the face of more severe weather events, outweigh any perceived vehicle instability concerns.

1.0 Introduction

The impact of climate change in terms of rainfall intensity, duration, and frequency on roadway design as it relates to surface drainage has yet to be addressed. The purpose of this paper is to discuss the implications of climate change on the provision of adequate road cross slope as it relates to geometric design and road safety. The paper explores whether there should be consideration for the adoption of increased cross slope to better accommodate climate change impacts.

The importance of risk of the highway infrastructure due to climate change has been recognized nationally by the *Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol* and internationally by the *ISO 310000 Risk Management* standard. Uncertainty in the field of infrastructure design is outlined in the American Society of Civil Engineers (ASCE) *Manual of Practice No. 140 – Climate Resilient Infrastructure Adaptive Design and Risk Management* (1).

In Canada, the British Columbia Ministry of Transportation and Infrastructure (BCMoTI) is developing climate change-resilient designs for highway infrastructure in British Columbia (BC). They have noted that climate change impacts are being felt in communities across the province with more frequent and intense weather extremes and climate related events causing damage to infrastructure, property, and ecosystems (3). Examples of climate parameters typically used during design on highway infrastructure include: rainfall, temperature, snow, wind, sea level, and stream/river flow (2).

Examples of design accommodations for climate change are provided in the BC guidelines, such as the Design Criteria Sheet for Climate Change Resilience (2). In estimating the hundred years peak flow rate for current design using the rational method, the flow rate has increased forty per cent to account for climate change. The structural design life for culverts less than a 3000 mm span shall be 75 years, as outlined the BC Supplement (5) to TAC (4).

Canada has seen annual precipitation increase steadily on aggregate by approximately 18 percent since the 1950s (6). This trend is forecast to continue with precipitation predicted to increase from 8 to 70% by the end of the century (7). Highest increases will be seen in the northern regions. Compounding the effects of overall increased precipitation is the likelihood of more frequent and intense rainfalls (7). Road design standards need to adapt to meet these changing environmental demands given that approximately 15% of vehicle crashes occur during periods when the road surface is wet (22).

2.0 Roadway Cross Slope: Best Practices

Surface drainage of water from the travel lanes of a road is accomplished through the provision of a combination of longitudinal slope as well as cross slope which is a camber in the travel lane(s) sloping downward typically from the centreline toward the shoulders. The Transportation Association of Canada (TAC) identifies the current best practices for cross slope design in their Geometric Design Guide for Canadian Roads (4). The most relevant points are as follows:

1. The normal roadway cross slope of 0.02 m/m on paved tangent roadways provides positive drainage to the curbs.
2. In areas where superelevation is developed and the cross slope rate is reduced to zero at the tangent runout, it is advantageous to maintain a longitudinal street grade of at least 0.6% to ensure that positive drainage flow is provided along the curb through this critical area.
3. In intersection areas, the normal cross slopes of the intersecting roadways may be reduced to avoid abrupt grade changes for through traffic. However, a minimum cross slope of 1.0% is desirable to maintain good surface drainage.
4. The algebraic difference in pavement cross slope between adjacent travelled lanes, or between through lanes and adjacent auxiliary lanes/turning roadways, as needed to maintain superelevation or provide drainage, are limited to the values discussed in Chapter 3 of the TAC Guide.
5. Some Canadian road agencies use a cross slope of 0.03 m/m on paved tangent sections of rural highways to preclude the risk of hydroplaning. Implementation of this cross slope results in an algebraic difference in pavement cross slope of 6%. Although this value is greater than the 4.0% maximum recommended [by AASHTO (8)], agencies using the 0.03 m/m cross slope have not reported any safety related concerns.

At issue is whether the guidelines prescribed by TAC are in keeping with changing climatic events, particularly more intense and frequent rainfall. To contextualize the TAC guidelines, a review of the literature was undertaken to synthesize cross slope standards used in other jurisdictions.

3.0 Cross Slope: Global Guidelines

The data presented in Table 1 show the standard travel lane cross slopes from a number of international jurisdictions. The data in the table are largely taken from an international survey published by the Transportation Research Board (9), however, other select countries supplement the original work. Most of the cross slopes that are presented as ranges are dependent on the road surface type with lower values stipulated for concrete or paved surfaces. For higher level roads values for cross slope between 2.0 and 3.0% are, by far, the most common. Most jurisdictions adopt steeper cross slopes for lower class roads which typically reflects the poorer characteristics of the road surface and reduced operating speeds.

Table 1: Typical Lane Cross Slope Design Values

Country	Roadway Classification			Reference
	Freeway	Arterial	Minor or Local	
Australia	2.0 to 3.0%	2.0 to 3.0%	2.5 to 4.0%	11
Brazil	2.0% concrete 2.5% asphalt	2.0% concrete 2.5% asphalt	2.0% concrete 2.5% asphalt	9
China	1.0 to 2.0%	1.0 to 2.5%	1.5 to 4.0%	9
France	2.5%	2.5%	2.5%	9
Germany	2.5 to 7.0%	2.5 to 7.0%	2.5 to 7.0%	9
Hungary	2.5%	2.5%	2.5%	9
Ireland	2.5%	2.5%	3.0%	18
Israel	2.0%	2.0%	2.0%	9
Japan	2.0%	1.5 to 2.0%	1.5 to 2.0%	9
New Zealand	2.0 to 3.0%	2.0 to 3.0%	3.0 to 4.0%	12
Poland	2.0%	2.0%	2.0%	9
Portugal	2.0% concrete 2.5% asphalt	2.0% concrete 2.5% asphalt	2.0% concrete 2.5% asphalt	9
South Africa	2.0 to 3.0%	2.0 to 3.0% rural 2.0 to 2.5% urban	2.0 to 2.5%	9
Spain	2.0%	2.0%	2.0 to 3.0%	9
Sweden		2.5 to 3.0%		9
Tanzania	2.5%	2.5 to 3.0%	3.0 to 4.0%	19
United Kingdom	2.5%	2.5%	2.5%	9
USA	1.5 to 2.0%	1.5 to 3.0%	1.5 to 6%	9
Venezuela	2.0%	2.0%	2.0% paved 4% gravel	9
Yugoslavia	2.5 to 7.0%	2.5 to 7.0%	2.5 to 7.0%	9

The results from an international survey of superelevation design guidelines by R. Lamm *et al.* (10) are synthesized in Table 2. Of relevance to this paper is that the authors reported that the minimum superelevations (typically 2.5%) are always substantiated by drainage requirements. The Swiss standard was adopted on the basis of a study on hydroplaning-related crashes which yielded a recommended minimum superelevation rate of 3.0% for all roads.

Table 2: Minimum and Maximum Superelevation Rates in Various Countries and Terrain

Country	Minimum Superelevation %	Maximum Superelevation %
Australia	2.0-3.0	Flat terrain: 6-7 General maximum: 10 Mountainous terrain: 12
Austria	2.5	6-7
Belgium	2.5	5-6
Canada	1.5-2.0	6-8
Denmark	1.5-3.5	6
France	2.5	General maximum: 7 Mountainous terrain: 6
Germany	2.5	7
Greece	2.5	Flat topography: 8 Flat topography w/o ice & snow: 9 Hilly/mountainous topography: 7
Ireland	2.5	7
Italy	2.5	7
Japan	1.5-2.0	10
Luxembourg	2.0-2.5	5-6.5
Portugal	2.0	6 (8)
South Africa	2.0-3.0	7
Spain	2.0	7 (10)
Sweden	2.5-3.0	5.5
Switzerland	3.0 (2.5)*	7
The Netherlands	2.0 (2.5)*	5 (7)
United Kingdom	2.5	5 (desirable max) 7 (absolute max)
United States	1.5-2.0	General max in areas with: snow/ice: 8 No ice/snow: 10 Exceptional cases: 12
	2.5	Flat topography: 8 Flat topography w/o ice/snow: 9 Hilly/mountainous: 7

Australia Road Crossfall

The Australian Geometric Design Guides published by Austroads (11) notes the following guidelines for pavement crossfalls (cross slope) for various surface types on tangent sections of roadways:

Table 3: Typical Australian Pavement Crossfall on Tangents

TYPE OF PAVEMENT	CROSSFALL %
Earth, loam	5.0
Gravel, water bound macadam	4.0
Bituminous sprayed seal	3.0
Asphalt	2.5 – 3.0
Portland cement concrete	2.0 – 3.0

The Austroads guide (11) makes an argument that a 2.0% cross slope (as prescribed by the Canadian TAC guidelines) is generally insufficient by noting that:

"Crossfalls flatter than 2.0% do not drain adequately, and even 2.0% should only be prescribed for concrete pavements where levels and surface finish are tightly controlled. Unless compaction and surface shape are well controlled during construction, pavements with less that 2.5% crossfall will hold small ponds on the surface, which many cause potholes to develop and hasten pavement failure. Rutting of the pavement is also more likely to hold water, increasing the risk of pavement deterioration and vehicle aquaplaning when the pavement crossfall is less that 3.0%."

In addressing the algebraic difference that cross slope creates when crossing the crown line, Austroads (11) notes that:

"On straight, two-lane two-way roads, a crown is often centrally placed to shed water to the edges of the road. A two metre rounding may be used to join the two opposite crossfalls, as shown in Figure [1] to maintain stability of vehicles."

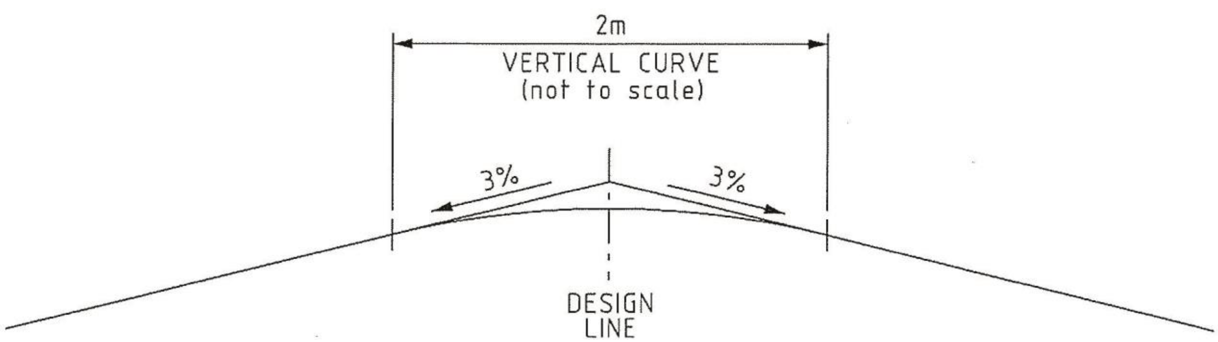

Figure 1: Two Metre Rounding Across Crown Line [Source (11)]

As trucks cross the crown line, they are subjected to significant destabilising forces, which can lead to a loss of control. The extent of these forces depends upon the length of the crown, the change in crossfall, the crossing angle, the speed of the vehicle and the general stability of the truck. Because of these destabilising forces, only crown lines parallel to the traffic lanes and located along the lines of traffic lane edges, are to be used.

The 6.0% grade change shown in Figure [1] should not be exceeded as this is close to the limit of stability for some trucks. The two metre rounding is appropriate for changes in grade from 0 to 6.0%.

One or more crown lines may be introduced on wide, flat pavement where flow depths exceed desirable limits. The function of the crown is to decrease the length of drainage surface flow paths, thereby reducing the depth of water on the pavement."

New Zealand Crossfall

The New Zealand (12) Transit Agency recommends the following typical pavement crossfalls which are generally in line with the Australian guidelines, but more aggressive than those prescribed by TAC:

Table 4: Typical Pavement Crossfalls

ROAD SURFACE	TRAFFIC LANE %	SHOULDER %
CEMENT CONCRETE	2.0 – 3.0	2.0 – 4.0
ASPHALTIC CONCRETE	2.5 – 3.0	2.5 – 4.0
CHIP SEAL	3.0 – 4.0	3.0 – 4.0
UNSEALED	3.5 – 4.0	4.0 – 5.0

On tangent sections of road, sealed shoulders should normally have the same crossfall as the adjacent traffic lanes. However, in areas where heavy rains are expected, shoulder crossfalls may be made 1.0 – 2.0% steeper than those used for the traffic lanes, to assist in draining the pavement surface quickly.

Ireland Road Camber

The Irish Road Link Design guide (18) stipulates that "the road crossfall or camber shall be 2.5%, falling from the centre of single carriageways, or from the central reserve of dual carriageways, to the outer channels". In keeping with similar practices in several other jurisdictions it goes on to note that "on minor roads where the quality of pavement laying is unlikely to be high, the minimum crossfall shall be 3%".

Tanzania Cross Slope

The United Republic of Tanzania specifies varying cross slopes that depend on the road class and surface type in their Road Geometric Design Manual (19). Higher level roads are surfaced with asphalt and require a normal cross slope of 2.5%, while lower class roads finished with either surface dressing or stone paved will be built with a 3% cross slope. Finally, low volume gravel roads are built with a 4% cross slope. They follow guidance from the Southern African Transport and Communications Commission for a maximum slope change when crossing over the crown line. This guidance stipulates a maximum algebraic difference of 5-8% for speeds of 20-30 km/h, 5-6% for 40-50 km/h, and 4-6% for over 60 km/h.

4.0 Roadway Hydroplaning

A road's inability to adequately shed water from the travel lanes can allow sufficient water depths to accumulate that may result in hydroplaning to occur depending on whether other conditions such as vehicle speed are met. Dr. John Glennon has conducted extensive research into roadway hydroplaning, cross slope, and rutting (13, 14, 15). As presented in *Roadway Hydroplaning – The Trouble with Highway*

Cross Slope (13), he notes that "although several vehicle, roadway, and environmental factors affect the probability of hydroplaning, a general rule of thumb for rural highways is that hydroplaning can be expected for speeds above 72 km/h where water ponds to a depth of 2.54 mm or greater, over a distance of 9.10 m or greater."

Glennon (13) notes that, "Although hydroplaning is a very complex phenomenon, it is known to be associated with several factors. The likelihood of hydroplaning on wet pavements increases with roadway and environmental factors that increase water depth and with driver and vehicle factors that increase the sensitivity to water depth as follows:

Roadway Factors (affecting water depth)

- Depth of Compacted Wheel Tracks
- Pavement Microtexture
- Pavement Macrotexture
- Pavement Cross-slope
- Grade
- Width of Pavement
- Roadway Curvature
- Longitudinal Depressions

Environmental Factors (affecting water depth)

- Rainfall Intensity
- Rainfall Duration

Driver Factors (affecting sensitivity to water depth)

- Speed
- Acceleration
- Braking
- Steering

Vehicle Factors (affecting sensitivity to water depth)

- Tire Tread Wear
- Ratio of Tire Load to Inflation Pressure
- Vehicle Type"

Glennon further notes that combinations of roadway factors which are particularly susceptible to hydroplaning are:

- "Higher grades draining downhill in wheel ruts to a sag with little or no cross slope.
- Wide pavements on grade with little or no cross slope.
- Pavement surfaces with little texture and little or no cross slope.
- Roadway curve transitions on wide pavements with little or no cross slope.
- Roadway curve transitions on steeper downhill grades with little or no cross slope.
- Deeper wheel ruts with little or no cross slope.
- Long downhill grades where water is dammed along an overgrown turf shoulder and builds up until it reaches a highway curve transition where it flows in sheets across the roadway.
- Other combinations of the above."

In Canada where inadequate cross slope has resulted in a prevalence of hydroplaning, one mitigative approach has been to install warning signs as show in Figures 2 and 3. The effectiveness of these warning signs is unknown.

Figure 2: Roadway Hydroplaning, Warning Sign

Figure 3: Roadway Hydroplaning, Warning Sign

Other roadway sections in Canada where hydroplaning has contributed to crashes are exit gores and the tangent between reverse curves, where lack of cross slope results in water ponding and the formation of black ice.

Glennon (13) concludes, based on his “research findings and in consideration of pavement irregularities (settlements, wheel ruts, etc.) that seem all too common, AASHTO should consider recommending 2.0 – 2.5% minimum cross slopes to minimize the propensity for hydroplaning, particularly for high-speed roadways.”

With respect to ruts, Glennon (14) has noted that “when considering wheel ruts that may need attention, pavement cross slope is paramount. When the pavement cross slope is relatively flat, relatively small wheel rut depths may be problematic, particularly at higher speeds. Conversely, higher cross slopes tend to be less sensitive to the hydroplaning contribution of pavement wheel ruts.”

Reference (14) includes critical rut depths for various cross slope and vehicle speed and reference (15) provides guidance on measuring pavement wheel rut depths to determine maximum water depths.

An increase from 1.5 or 2% to a 3% cross slope will result in faster surface drainage of water. The extent of this improvement can be roughly estimated on the basis of the Manning equation which states (16):

$$V = \frac{k}{n} R_h^{2/3} S^{1/2}$$

where: V is the cross-sectional average velocity (m/s)

N is the Gauckler-Manning coefficient

R_h is the hydraulic radius (m)

S is the slope of the hydraulic grade

K is a conversion factor between SI and Imperial units

This equation stipulates that the time of concentration calculations for sheet flow, or shallow concentrated flow) is dependent on the square-root of the slope. Consequently, a 3% cross slope for a travel lane would result in an evacuation of surface water that is approximately 42% faster than a 1.5% cross slope, and 23% faster than a 2% cross slope.

5.0 New Brunswick Department of Transportation & Infrastructure Experience with a 3.0% Cross Slope

Prior to the early 1990s, the New Brunswick Department of Transportation and Infrastructure (NBDTI) had a long-standing in-house design standard to use 2% cross slopes on roads paved with asphalt and 3% for those surfaced with chipseal or gravel. Following a spate of collisions where hydroplaning was identified as a major contributing factor, the Department investigated and found that in the areas where the collisions occurred, the full 2% cross-slope often had not been achieved. Furthermore, wheel rutting was particularly problematic during this time period as the Department struggled with their asphalt mixes and lacked budget for rehabilitation projects. Relatively flat cross slopes were found to prevent wheel ruts from draining properly thereby establishing conditions that permitted hydroplaning. This prompted the Department in 1993 to adopt a more aggressive 3% cross-slope for all paved road surfaces with the objective of improving the drainage from the travel lanes and wheel ruts. Anecdotal evidence from the maintenance crews has supported the premise that the lanes built with a 3% cross slope drain much better. Furthermore, improvements in asphalt mix design have likely played a role by reducing rutting.

By allowing 3% cross slopes with a construction tolerance typically of 0.5%, it is possible in New Brunswick for an algebraic difference of up to 7% to be created at the crown. This is contrary to AASHTO and TAC’s position that an algebraic difference greater than 4% may reduce stability for vehicles with high centers of gravity (4, section 3.5.2). While NBDTI will endeavor to fix cross slopes greater than 3% under resurfacing contracts, they have not identified truck instability as a safety-related concern. Interestingly, it was noted above by Austoads that the abruptness of a typical crown can be softened somewhat during the paving process by introducing a rounding across the crown. A paving machine's screed can be bowed slightly thereby creating an arc rather than an abrupt transition at the crown. That said, the typical practice in New Brunswick is that each lane is usually paved separately from the crown towards the edge which does not improve the transition at the crown. There may be some benefit from the paving roller which tends to knead/flatten the joint between adjacent asphalt mats at the crown when they are being laid resulting in a slightly smoother transition than section design drawings depict. On whole, the Department has taken the position that the benefits of improved drainage outweigh any concerns related to vehicle operational concerns and instability crossing over the crown. There is currently no definitive empirical evidence to support or contradict this position.

The effectiveness of adopting a more aggressive cross slope in reducing incidences in hydroplaning is of interest, however, there are many confounding variables that make it problematic to isolate its impact. The following figures synthesize the prevalence of hydroplaning in New Brunswick over the past 25 years and help to illustrate the difficulty of documenting the impact of the shift to a 3% cross slope.

In Figure 1, the frequencies of those police-reported collisions where hydroplaning is identified as a major contributing factor are plotted dating back to 1993. It is evident that in the early 1990s the frequencies are very low compared to subsequent years. This is attributed to a major initiative by the Department in the mid-1990s to provide extensive training for enforcement officers who are responsible for the coding of the contributing factors for motor vehicle collisions. The data show a relatively consistent upward trend since the late 1990s. The average annual total for about the last 5 years of observation is 133 collisions. These data are reflective of the entire road network in New Brunswick which is currently constructed with a mixture of 2 and 3% cross slopes so any benefits of the 3% standard cannot be understood.

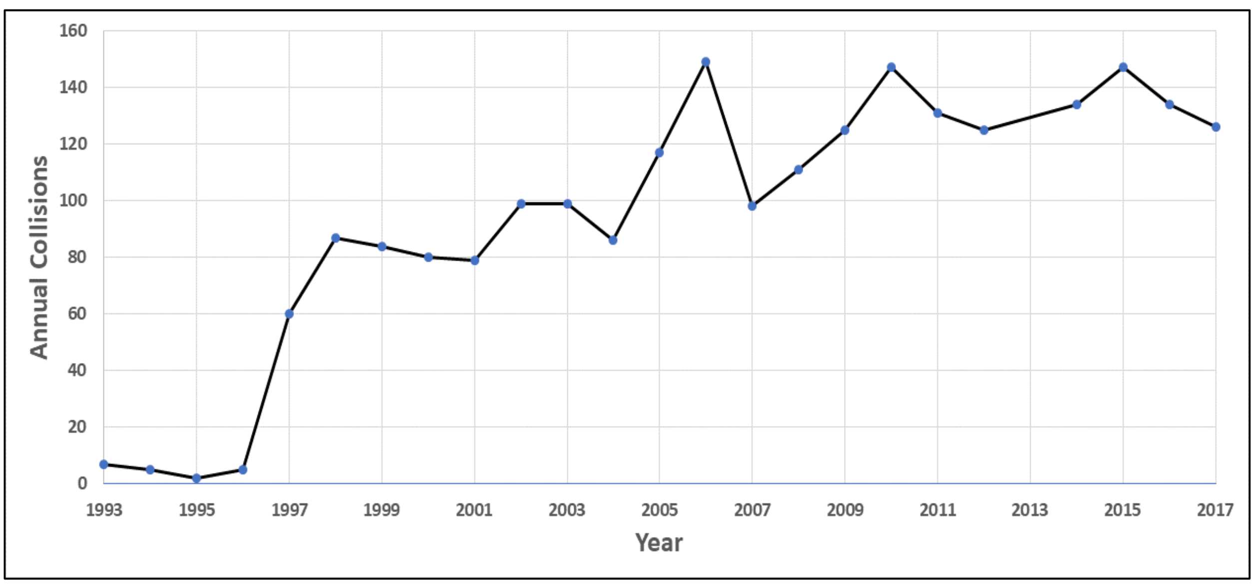

Figure 4: Frequency of Hydroplaning Collisions in New Brunswick

To perhaps better understand the implications of a 3% cross slope standard an analysis of hydroplaning collisions on the main arterial through the province, the TransCanada Highway (TCH, Route 2), was undertaken. This highway went through a major reconstruction program after the adoption of the 3% cross slope standard and provides an interesting case study when considering the effect of this standard modification on hydroplaning collisions. It is noteworthy that about 30% of all reported hydroplaning collisions in New Brunswick occur on this one facility.

The data in Figure 5 depict the changes in annual hydroplaning collisions throughout the 514 kilometre arterial. If the late 1990s (post police training) are considered the benchmark it should be noted that the cross slope for most of this facility was 2% during this period. In 2001 a major twinning project of 195 kilometres fully opened which converted a large section of this facility to a 3% cross slope. It is evident that despite this geometric change, annual hydroplaning collisions remained relatively constant. In 2007, another 98 kilometre section of reconstructed TCH opened in the western part of the province, thereby again increasing the proportion of the route that was upgraded with a 3% cross slope. Unexpectedly, the frequency of hydroplaning collisions rose on this facility and remain relatively high.

Interestingly, a similar upgrade project was undertaken for Route 1 that was completed in 2012. The results of hydroplaning frequencies were similar to the Route 2 experience in that despite the introduction of a stronger 3% cross slope, hydroplaning collisions rose following the completion of the project. To better understand these unexpected trends, the impacts of other explanatory variables were investigated.

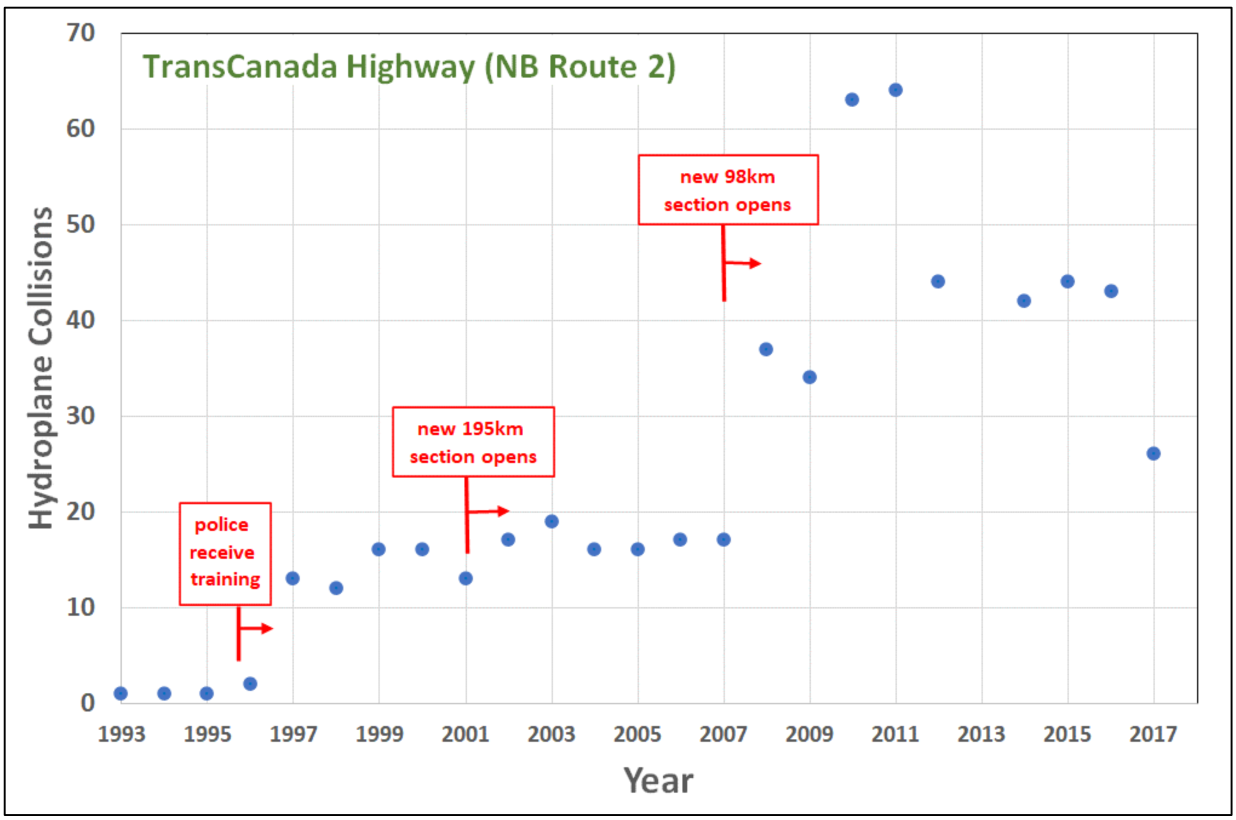

Figure 5: Annual Hydroplaning Collisions on the N.B. Trans-Canada Highway

The data in Figure 6 depict the average annual hydroplaning collisions over the latest 5-year period for each of the different speed zones where the collision occurred. It is shown that, by far, the greatest number of hydroplaning collisions have occurred in the highest speed zones of 100 and 110 km/h. In fact, 53% of hydroplaning crashes happen in a 110 km/h speed zone and a further 18% in a 100 km/h zone. This is consistent with a long-standing generalized relationship that approximates the velocity at which hydroplaning can occur given by (17):

$$V_{p\,(mph)} = 10.35\sqrt{p}$$ where, p is the tire pressure in psi

Assuming a typical tire pressure in passenger vehicles of 33 psi, the above relationship would yield an approximate minimum hydroplaning speed of 59 mph (or 96 km/h). It is noted that more recent research recognizes that hydroplaning speed is dependant on many variables in addition to tire pressure including stormwater runoff depth (or water film thickness), tire tread depth, average pavement texture depth, and others (20). At operating speeds of 80 to 100 km/h, models based on Hubner *et al.* (21) estimate that water film thickness need only be approximately 1 to 2.5mm in order for hydroplaning to occur.

It is likely that if the data were normalized for exposure in terms of vehicle-kilometres of travel, the over-representation of the highest speed zones would be even more exaggerated. When one considers that the speed limits of the TCH (in Figure 5 above) were increased to 110 km/h for the reconstructed sections, **it is evident that higher operating speeds is likely an overriding factor that has led to a substantial increase in hydroplaning collisions despite the potential benefit of an increased cross slope.**

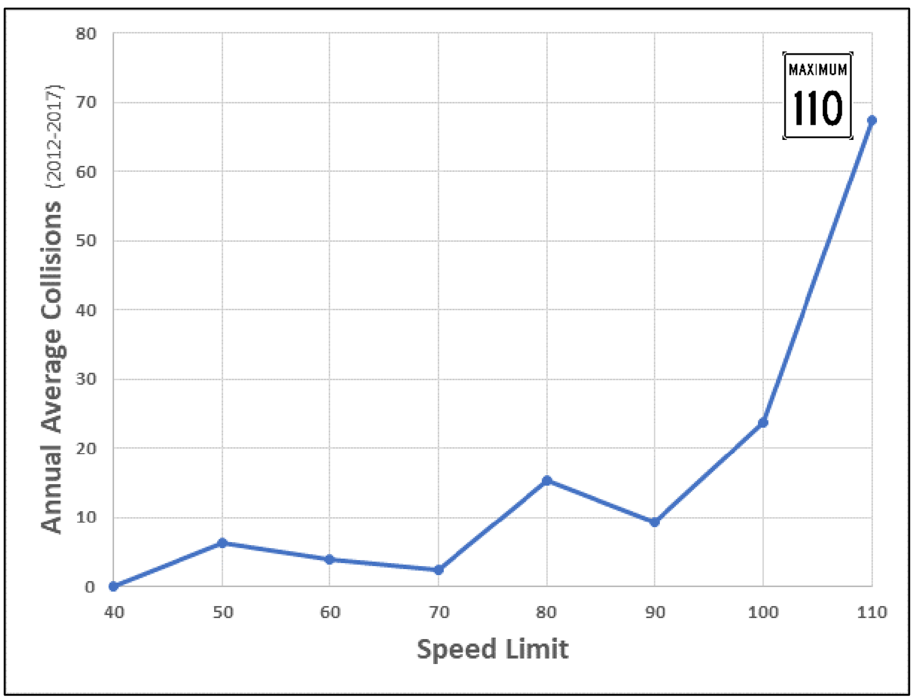

Figure 6: Annual Hydroplaning Collisions versus Posted Speed Limit

The data in Figure 7 provide a contrast in the incidence of hydroplaning collisions on asphalt surfaced roads versus those with a chipseal surface. In general, roads with an asphalt surface are built to a higher design standard typically resulting in higher operating speeds. It is clear that the vast majority of hydroplaning collisions are attributed to roads surfaced with asphalt even though chipseal roads represent the majority of the road infrastructure in New Brunswick with 9,213 kilometres (versus 7,010 kilometres of asphalt roads). It is noteworthy that the hydroplaning collision *rate* for asphalt roads is

18.8 versus only 0.8 collisions/1000km for chipseal roads. Again, this is most likely attributed to generally lower operating speeds on chipseal roads.

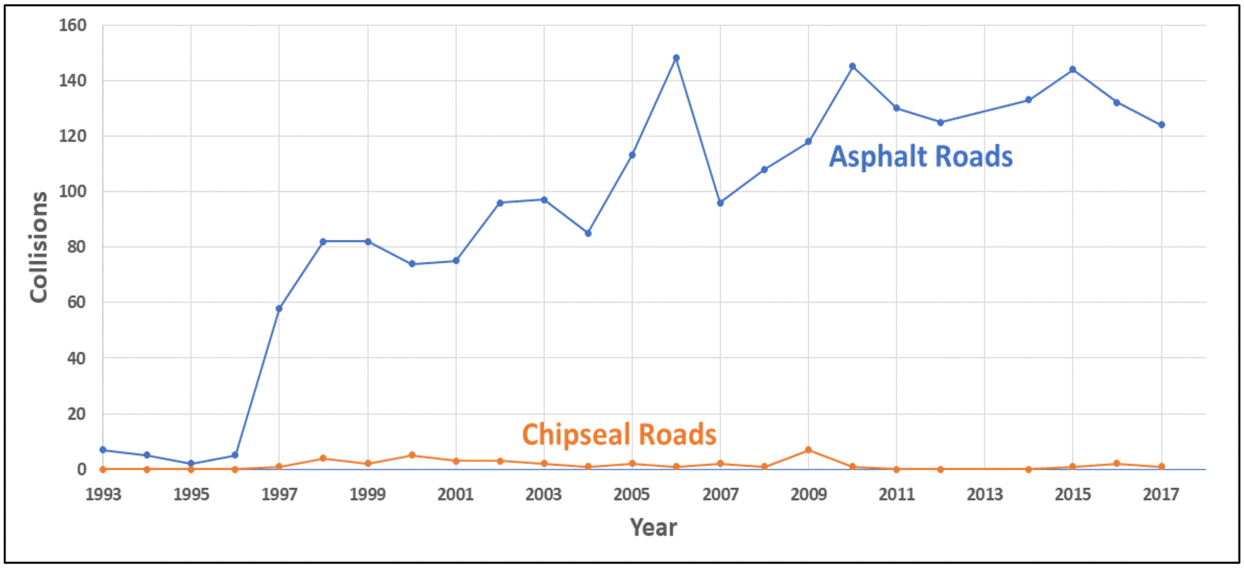

Figure 7: Hydroplane Collisions by Road Surface Type

Isolating the safety-related impacts of an increased cross slope on road collisions is very difficult given the conflating impacts of many other variables. Road improvement projects, such Route 1 and 2 described above, may change the cross slope, but are normally accompanied with many other geometry changes which can make it difficult to isolate the impact of the cross slope attribute. While there have been a few smaller rehabilitation projects in New Brunswick which have resulted in few geometric changes apart from the cross slope, the incidence of hydroplaning on shorter sections is often too small to draw any meaningful conclusions.

6.0 Summary and Conclusions

The following points synthesize the main points presented in this paper:

- Climate change observations indicate that highway design must take into account more frequent and intense rainfall.
- Cross slopes of greater than 2.0% in many countries and New Brunswick have not resulted in operational problems of heavy trucks with a high centre of gravity crossing the crown line.
- Cross slopes of up to 3.0% shed water approximately 23 to 42% faster than cross slopes of 1.5 – 2.0% and are a countermeasure to mitigate hydroplaning.
- There is a tendency for cross slope guidelines to allow for steeper values on lower speed facilities when, in fact, the need for improved drainage to prevent hydroplaning is greatest on the highest speed roads.
- Although there have been many advances in asphalt mix design over the past few decades, rutting continues to be an issue in different parts of the country thereby increasing the need to provide better drainage from travel lanes.

- The authors suggest that TAC initiate a research project to evaluate the provision of cross slopes greater than 2.0% to mitigate the impact of climate change as a contributing factor to hydroplaning.

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