R.V. Anderson Associates Limited
engineering · environment · infrastructure

445 Urquhart Crescent
Fredericton New Brunswick E3B 8K4 Canada
Tel 506 455 2888 Fax 506 455 0193
www.rvanderson.com

October 23, 2009 091971

Stantec
3 Spectacle Lake Drive
Dartmouth, NS
B3B 1W8

Attention: Ms. Shannan Murphy, B.Sc., Project Manager

Dear Ms. Murphy:

Re: **Hydrotechnical Review of Highway 104 Antigonish West River Bridge Options**

At the request of Mr. Dwayne Cross, P.Eng., Senior Highway Planning Engineer with the Nova Scotia Department of Transportation and Infrastructure Renewal, Hydro-Com Technologies, a division of R.V. Anderson Associates Limited, has performed a hydrotechnical review of the proposed new bridges over the West River on Route 104 near Antigonish, Nova Scotia. The objectives of this assignment were to identify and quantify the hydrologic, hydraulic and fluvial effects associated with shortening the span of the proposed new bridges, the provision of design recommendations for the hydraulic opening of the proposed new bridges, and the formulation of a “specialist opinion” for presentation to regulatory agencies. Our hydrotechnical review included consideration of the components listed below, the results of which are presented in the following sections:

- a review of the local hydrology (including the determination of design flows and an assessment of the predicted effects of climate change),
- a review of the potential effects of tides and storm surges at the project site,
- an assessment of the effects of the proposed new bridges on local flood levels,
- an assessment of the scour potential at the site of the proposed bridges, and
- a review of the local ice regime and an assessment of the expected effects of the proposed new bridges on ice and debris passage.

The results of the above analyses are summarized below and a recommendation for a minimum bridge opening is presented at the end of this letter.

1.0 Hydrology and Design Flows

The Antigonish West River watershed is 330.6 km^2 upstream of the proposed bridges site, with a drainage length of 41.6 km and a general slope at the crossing area of 0.27 %. The hydrology of the Antingonish West River watershed was first studied by reviewing various hydrological reports, four (4) of the most pertinent are listed and summarized in Appendix A. Five (5) hydrometric stations in the eastern portion of mainland Nova Scotia were selected for use in determining flood flows for the West River at the proposed bridges site, all with more than 10 years of data and on natural flow (unregulated) watercourses (see Table 1).

Station Number	Station Name	Drainage Area km^2
01DR003	Rights River near Antigonish	64.2
01EO003	East St. Marys River at Newtown	282
01DR001	South River at St. Andrews	177
01DP004	Middle River Of Pictou At Rocklin	92.2
01EO001	St. Marys River at Stillwater	1350

Table 1: Nearby Hydrometric Stations

Of the five stations, three stations drain to the Northumberland Strait, while two drain to the Atlantic Ocean. The Rights River near Antigonish (station no. 01DR003) produced the largest unit flows but had only 11 years of instantaneous flood flow data and is more urbanized than the other watersheds. The St. Marys River at Stillwater (Station No. 01EO001) produced the smallest unit flows, had the largest drainage area and drains to the Atlantic Ocean. Flood flow estimates obtained using CFA-3 for the 5% annual exceedence probability (20-year return period), 2% annual exceedence probability (50-year return period), and 1% annual exceedence probability (100-year return period) were tabulated for each station. These values were then prorated by a simple ratio of drainage areas to derive estimates for the West River at the proposed Route 104 bridges site.

The prorated values were averaged for three stations with periods of record > 20 years, the three stations within the Gulf of St. Lawrence drainage, and for all five stations. It was found that the averaged values for all five stations (using prorated flows determined using GEV, 3PLN, LP3, Wakeby and non-parametric distributions) were intermediate between the other averaged values, and they were chosen as the preliminary design values for the study. These preliminary design values were multiplied by a factor of approximately 11% to account for the predicted effects of climate change during the 21st century (based on the 2086 anomaly of 5-day maximum precipitation for longitude 62.14° and latitude 45.62° from the GCM AR4.NCARPCM model output for scenario SR-B1, extremes). The resulting recommended design flows are summarized in Table 2.

Return Period	Annual Exceedence Probability	Flow, m^3/s considering climatic change
2 year	0.50	**180**
20 year	0.05	**470**
50 year	0.02	**605**
100 year	0.01	**720**

Table 2: Design Flows for the Antigonish West River at the Proposed Bridges Site

As Route 104 is part of the primary 100 series highways in Nova Scotia, we recommend that the 100 year return period flow with an allowance for climate change be used as the design flow for the proposed new bridges, and have used the estimated flow of 720 m^3/s as the basis for our assessments of flood levels, scour depths and ice/debris passage.

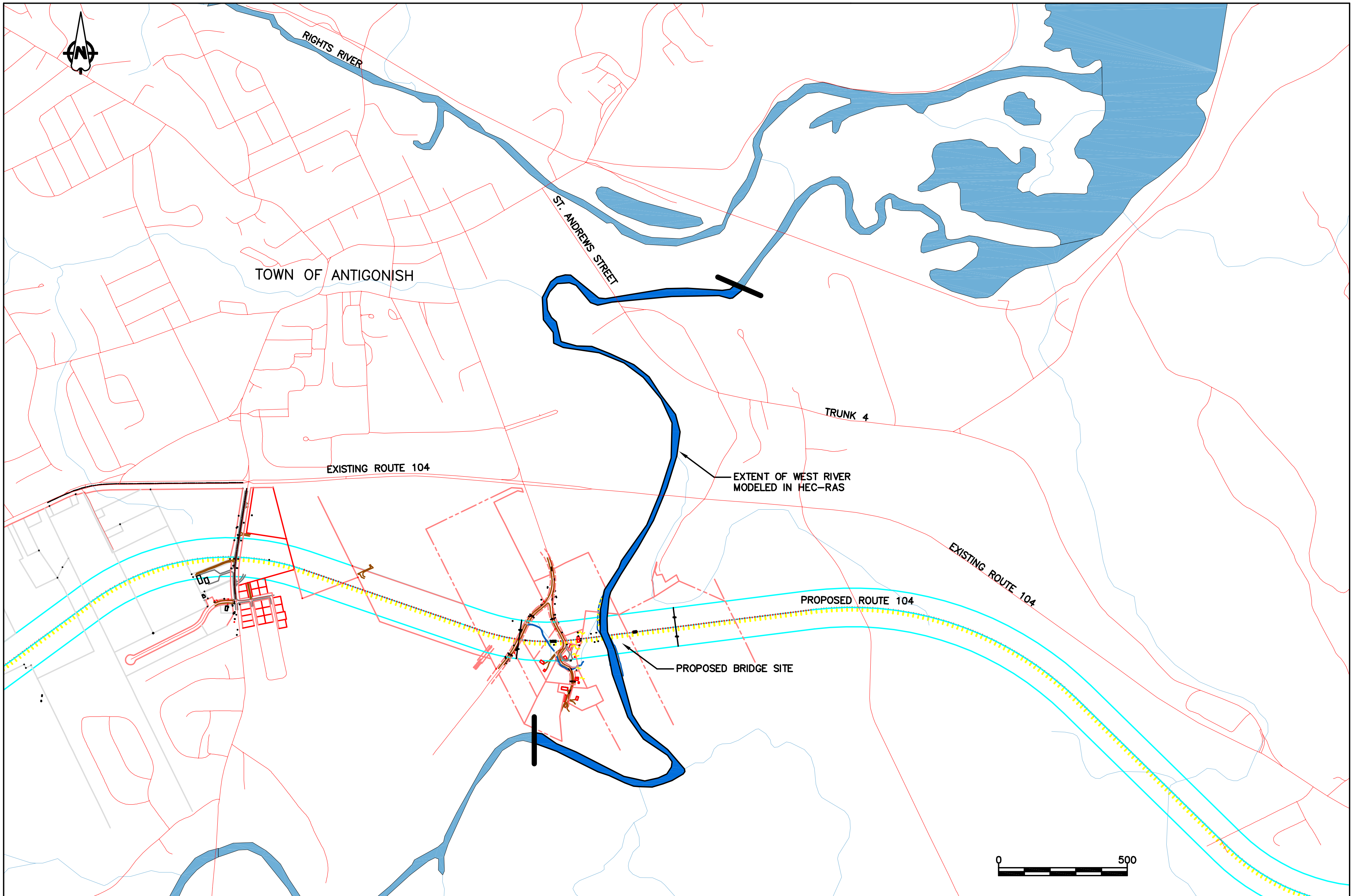
2.0 Tides and Storm Surges

The potential effects of tides and storm surges on the hydraulic performance of the proposed bridges were assessed by comparing the maximum water level elevations of historic tides and storm surges at the mouth of the West River to the channel invert elevations at the site of the proposed bridges crossing. Information on tides and storm surges was extracted from the Tides and Current Tables published by the Federal Department of Fisheries and Oceans. Using the Tidal Reference Port at Pictou, NS (index number 1630) and the St. Georges Bay Secondary Port at Antigonish Harbour (Index Number 15990), the higher high water of a large tide elevation was estimated to be +0.4 m (geodetic datum), while the recorded extreme elevation (storm surge) was estimated to be +1.4 m (geodetic datum).

As the invert elevation of the West River channel at the site of proposed bridges is approximately +3.5 m (geodetic datum), the effects of tides and storm surges on the hydraulic performance of the proposed bridges were deemed to be insignificant and were excluded from subsequent analyses.

3.0 Flood Levels

The backwater effects of the proposed Route 104 bridges over the West River near Antigonish were analyzed using a HEC-RAS computer model. Using data from NSTIR bridge surveys to define the channel profiles, and provincial contour mapping to determine the extents of floodplains, the West River was modelled from near Salt Springs (upstream of the proposed bridges) to the river outlet in St. Georges Bay (see Figure 1). The modelled stretch of the West River included the existing bridge on Route 104 and the existing bridge on Trunk 4, and therefore the modelling output incorporates the effects of these existing bridges. The peak flows presented in section 1.0 and the highest high tide elevation of +0.4 m (geodetic datum) at the downstream boundary of the model were used as primary model inputs, while spans for the proposed new bridges of 241 m (span of the originally proposed bridges with three piers and two abutments), 90 m, 70 m and 50 m were modelled. In order to provide context for the span length of the proposed new bridges, it should be noted that the existing bridge on Route 104 located approximately 500 m downstream of the proposed new bridges has a total span of approximately 38 m with a single centre pier and two abutments, and that the existing bridge on Trunk 4 located approximately 2 km downstream of the proposed new bridges has a total span of 46.8 m without any piers.



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WEST RIVER, ANTIGONISH COUNTY, NOVA SCOTIA

Project No.	Date
091971	Sept. 17, 2006
Scale	DWG No.
1 : 20 000	Figure 1

Table 3 presents the water levels immediately upstream (64 m) of the proposed bridges as calculated by the HEC-RAS model for various return period flows and the four (4) bridge spans listed above.

	Return Period of Flows			
Bridge Span (m)	**2 year**	**20 year**	**50 year**	**100 year**
50 m	6.70 m	8.18 m	8.72 m	9.17 m
70 m	6.67 m	8.08 m	8.58 m	8.97 m
90 m	6.66 m	8.03 m	8.51 m	8.88 m
Original Span (241 m)	6.64 m	7.94 m	8.37 m	8.71 m

Table 3: Water Level Elevations Upstream of Proposed New Bridges

The predicted 100-year water level increases due to the reduction of the span for the proposed bridges from a 241 m span to 90 m, 70 m and 50 m spans are 0.17 m, 0.26 m and 0.46 m, respectively. These water level increases are relative to the water levels at the proposed bridge site for existing conditions (or a clear span), as obtained from modelling results. In the interpretation of these water level increases it should be noted that these backwater effects are expected to be limited to the 1.0 km reach of the West River immediately upstream of the proposed bridges (i.e. they are reduced to near zero water level elevation increases within this reach), and that due to the complete lack of existing and expected future development along this 1.0 km reach, the consequences of these water level increases are believed to be negligible. The proposed bridges are not expected to aggravate or alleviate local flooding in Antigonish.

Based on the above magnitude of backwater effects, and a reasonable degree of conservatism when comparing the span of the proposed bridges to the spans of the two existing downstream bridges, we recommend a minimum bridge span of 70 m for the proposed new bridges. The discussions presented below on scour potential and the local ice regime are based on a bridge span of 70 m.

4.0 Scour Potential

The scour that could occur at the site of the proposed bridges consists of: degradation scour (the general lowering of the channel bed due to the formation of a cut-off in an upstream channel bend), the movement of bed forms (driven by the natural downstream movement of sediment and bed material), contraction scour (due to increased flow velocities associated with the contraction of the channel width) and pier/abutment scour (local scour immediately in front of piers and abutments due to local turbulence). As degradation scour and the movement of bed forms are natural processes that would occur if a bridge is present or not, scour associated with these natural process were not considered as part of the quantification of the reduced bridge span effects on the local river morphology, but were quantified as a general illustration of the maximum potential scour depth. The following sub-sections present our approach and findings for each of the types of scour identified above.

Lateral shifting of the channel of the West River has occurred, as evinced by the development of a cut-off in an upstream channel bend. The proposed bridges will act as a constraint to the lateral movement, which is a natural process expected to continue to occur upstream and downstream of the proposed bridges. As the proposed bridges have a clear span over the main channel, and abutments tie into banks higher than the design flood levels, flow conveyance cannot bypass the waterway openings of the bridges.

The scour potential at a channel section is a function of the bed material size. During the site inspection performed on August 20, 2009, the average size of the bed material in the west river was observed to range from approximately 30 mm (in pools) to 300 mm (on riffles). Methodologies that consider the size of bed material in the estimation of scour have used this range of sizes in their calculations.

a. Degradation Scour

The magnitude of degradation scour was estimated using: the Mean Velocity Method, the Competent Velocity Method and published values of permissible velocity, as well as morphological information.

The mean velocity method is a simplistic method in which the mean velocity through the waterway opening at various flood flows is equated to the mean approach velocity at cross-sections immediately upstream of a bridge. It does not take into account the characteristics of the bed material, and is generally considered to be conservative. The competent velocity method assumes that general scour will occur when the mean velocity through the bridge opening exceeds flow velocity needed to erode bed material of a given size (the competent velocity). The results from the competent velocity method are approximate and considered overly conservative if the flow of sediment of the river is substantial. The mean permissible velocities as presented in the 2001 TAC Guide to Bridge Hydraulics and the 1999 AASHTO Highway Drainage Guidelines (metric edition) indicate that mean flow velocities greater than 2.0 m/s are needed to transport material at the site of the proposed bridges on the West River.

The results from the Mean Velocity Method, the Competent Velocity Method and the published values of permissible velocity do not predict degradation scour.

Based on a review of the morphological information for the West River at the site of the proposed bridges, it is considered likely that the West River will cut through the bend upstream of the proposed bridges crating an oxbow. This is expected to result in steeper channel slopes at the bridge site and channel adjustments downstream (degradation scour) with an estimated magnitude of 0.1 m.

Based on the above results, the magnitude of degradation scour at the site of the proposed bridges is estimated to be 0.1 m. As mentioned previously, degradation scour is a natural process and should not be considered an effect of the proposed new bridges (either with a full 241 m span or a reduced 70 m span).

b. Bed Form Movement

The natural downstream movement of bed forms will result in a rising and falling of the channel bed elevation at a given location over time. Based on the survey information provided by NSTIR and field observations made on August 20, 2009, the height of the local bed forms on the West River near the site of the proposed new bridges was estimated to be 0.3 m. The magnitude of scour induced by the movement of bed forms was thus estimated at 0.3 m. Again, it should be noted that scour due to bed material movement is a natural process and should not be considered an effect of the proposed new bridges.

c. Contraction Scour

Scour initiated by changes in the flow cross-section of a river (either during normal flows or during flood flows) is termed contraction scour. The depth of contraction scour on the West River for the proposed new bridges with a span of 70 m was estimated using a modified version of the Laursen 1960 equation and the clear-water contraction scour equation. For the range of bed material sizes, a 100-year return period flow and a span of the proposed new bridges of 70 m, the clear water scour equation did not predict any contraction scour, while the modified Laursen 1960 equation predicted a scour depth of 0.68 m for the proposed upstream bridge and 1.51 m for the proposed downstream bridge. Large differences in predicted scour depths between different methods are not uncommon for situations where bridge abutments are not located within the main channel of a river crossing, and we recommend that the larger and more conservative predictions from the Laursen equation be used for this project.

d. Abutment Scour

As the configuration of the proposed new bridges consists of two abutments without any piers, only the depth of potential abutment scour was estimated. Based on the equation developed by T.W. Sturm and N.S. Janjua (ASCE Journal of Hydraulic Engineering, 120 (8): 956-972), the depth of abutment scour for the proposed new bridges was estimated to be negative, and thus no abutment scour is expected.

e. Scour Summary or "Total Scour"

In summary, the above information indicates a range of total combined scour depths at the site of the proposed new bridges of between 1.1 m and 2.0 m, with minor and localized widening of the channel at the bridge locations due to the adjustment of the existing channel banks in response to this lowering of the channel bottom. In the interpretation of this information, it should be noted that this total combined scour depth will consist of a semi-permanent 0.3 m to 0.4 m deep pool under the proposed bridges, with the remaining scour depth due to temporary contraction scour during major flood events (these temporary scour holes will be filled by natural bed load transport shortly following a major flood event). In the case of a full span over the flood plain and channel, there would be no contraction scour, but channel degradation and bed form movement may still occur.

Also of note is the fact that the proposed bridge crossings are located on a section of the West River that currently represents a riffle section, and that the construction of the proposed bridges will result in the formation of a semi-permanent pool at this location. The local alteration of the current pool-riffle sequence at the site of the proposed bridges is expected to result in a readjustment of the pool-riffle sequences between the proposed new bridges and the existing bridge on Highway 104. This readjustment is expected to take a few years and may destabilize existing river enhancement features in this reach of the West River.

5.0 Ice Regime

The local ice regime and the potential for the formation and/or aggravation of ice jams by the proposed bridges are ideally assessed by observing a number of ice runs during the winter and spring seasons. Generally, the observation of river ice conditions of two or more winter and spring seasons is preferred to characterize a river-ice regime, but this information is currently unavailable and our assessment is based on anecdotal information and a review of: the potential ice supply, the ice hydrology, the presence of likely locations for formation of ice jams, a review of the bottom chord clearance of the proposed bridges and visual evidence of ice effects in the field. Details of the above reviewed items are presented below, followed by a summary conclusion regarding the expected effects of shortening the spans of the proposed bridges on the local ice regime.

Anecdotal information on the local ice regime indicates that ice runs and minor ice jams are common and that ice historically jams at the sharp bend in the West River between the existing Highway 104 bridge and the bridge on Trunk 4. These ice jams do result in flooding in Antigonish and are a concern during ice breakups.

The supply of ice from the West River to the site of the proposed bridges was estimated at 76 000 m^3. This was based on an approximate channel length of 3.6 km to a location on the West River just upstream of the Trunk 7 crossing, an average channel width of 35 m, and an average ice thickness of 0.6 m. The upstream limit was chosen as the channel is depicted as narrowing near Salt Springs, thereby likely reducing the supply of upstream ice as the upstream ice is expected to jam at numerous (over 15) upstream river bends or become stranded on the flood plains and low-lying terraces along the river. The above estimated volume of ice is large enough to result in significant ice runs and form ice jams, and confirms the above anecdotal information. During ice runs, much of the ice may become stranded on flood plains. The proposed bridges are not expected to alter the possibility of ice storage.

The ice hydrology and the effect of regional climate on the ice season characteristics of the West River were assessed by reviewing the records of nearby hydrometric stations. Based on the results of this hydrometric records review the ice season of the West River is from late November to early April, and would normally last 80 to 100 days, with frequent occurrences of midwinter breakups.

The flows during breakup events are much less than design peak flood flows, and ice is expected to clear from the channel at flows less than the 20-year recurrence flood. This information indicates that ice breakup (and the associated ice runs and ice jams) is common on the West River, but that these breakup events rarely coincide with large flood flows and that the severity of the ice runs and ice jams are generally minor.

Generally, river-ice jams are more likely to occur at locations where the river-ice conveyance capacity is reduced by morphologic features such as sharp bends, decreases in channel slope, and constrictions (both natural and man-made), as well as at locations where moving ice meets an intact ice cover such as the point of inflow into a lake or reservoir. Based on a review of the West River near the site of the proposed bridges, the following likely sites for ice jams were identified:

- The sharp bend (approx. 90 m radius, 450 m channel length, and 250 m meander length) located approximately 350 m upstream of the proposed bridges. Ice passage over the land within the meander loop has been observed in the past, and ice may be transported across the flood plain at this meander or stranded on the flood plain, depending upon the magnitude of breakup flows. The formation of ice jams is highly likely at this location.

- The sharp bend (approx. 100 m radius, 400 m channel length, and 300 m meander length) located between the existing Highway 104 bridge and the bridge on Trunk 4. Again, ice passage over the land within the meander loop has been observed in the past, and ice may be transported across the flood plain at this meander or stranded on the flood plain, depending upon the magnitude of breakup flows. The formation of ice jams is highly likely at this location.

- The mild bend (approx. 400 m radius, 600 m channel length, and 525 m meander length) between the downstream proposed bridge and the existing Highway 104 bridge. The channel narrows slightly between the proposed bridges, but the top width of the channel reduces greatly (from 40 m to 15 m) at the bend approximately 150 m downstream of the proposed downstream bridge. The formation of ice jams at this location is less likely than the above two locations, and the large flood plain upstream of the existing Highway 104 bridge is expected to allow ice runs to dissipate and degrade.

The above information indicates a high likelihood of significant ice jamming immediately upstream of the proposed bridges and downstream of the existing Highway 104 bridge, a lower likelihood of minor ice-jam formation immediately upstream of the existing Highway 104 bridge, and very little likelihood of ice-jam formation at the site of the proposed bridges.

The water level elevation associated with the 20-year return period flow at the site of the proposed bridges (identified above as a likely maximum flow at ice breakup) and a 70 m span is estimated to be approximately 8.0 m, while the bottom chord elevation of the proposed bridges is above elevation 13.0 m. The 5.0 m clearance is adequate to minimize the risk of the bottom chord of the proposed bridges impeding the movement of ice.

Ice scars and vegetation trim lines provide indirect information on ice and water levels during past ice breakup and ice jamming events. They were identified during the field inspection of August 20, 2009, and were found to range between 1.0 and 2.0 m above bank-full elevation. This evidence supports the insight into the local ice regime inferred from the information presented above, and confirms the fact that the reach of the West River near the proposed new bridges is not prone to ice jamming.

In summary, the local ice regime is not expected to have significant effects on the proposed bridges, the proposed bridges are not expected to affect the local ice regime or the local movement of ice, and the proposed bridges are not expected to aggravate the local ice related flooding in Antigonish.

6.0 Conclusions and Recommendations

Based on the above information, we have drawn the following conclusions regarding the potential effects of reducing the span of the proposed new Highway 104 bridges over the West River near Antigonish:

1. Based on the width of the West River main channel at the crossing site of the proposed new bridges, and the hydraulic conveyance capacity of existing downstream bridges, we recommend a minimum span of 70 m for the proposed new bridges on Highway 104.

2. The proposed bridges with a 70 m span are predicted to increase the local flood level elevation during a 100 year return period flood (with allowances for climate change) by 0.26 m. The spatial extent of this increase in flood water levels is limited to the reach of the West River approximately 1.0 km upstream of the proposed new bridges. As no infrastructure is located along this 1.0 km reach, this predicted increase in flood level is deemed to be acceptable.

3. The proposed new bridges are predicted to result in the formation of a 0.3 m to 0.4 m deep permanent pool at the crossing site. The depth of this pool is predicted to increase temporarily to between 1.1 m and 2.0 m during flood events.

4. The above new pool will be located in what is now a riffle section. The formation of the new pool is expected to alter the existing pool-riffle sequence between the proposed new bridges and the existing Highway 104 bridge, and may destabilize existing river enhancement features in this reach of the West River. We recommend that following the re-establishment of a new pool-riffle sequence (expected to take a few years), the need to restore the river enhancement features be assessed.

5. The local ice regime is not expected to have significant effects on the proposed bridges; and the proposed bridges are not expected to affect the local ice regime or the local movement of ice, and the proposed bridges are not expected to aggravate the local ice-related flooding in Antigonish

In summary, the hydrotechnical effects of shortening the span of the proposed new Highway 104 bridges over the West River near Antigonish from 241 m to 70 m are not predicted to be significant; and no hydrotechnical reasons where identified that would prevent the Nova Scotia Department of Transportation and Infrastructure Renewal from reducing the span of the proposed bridges.

I trust this information serves your current needs. If you have any questions or require additional information, please contact us at your convenience.

Yours very truly,

HYDRO-COM TECHNOLOGIES
a division of R.V. Anderson Associates Limited

Hans Arisz, M.Sc.E., P.Eng.
Associate Director

Encls.

Appendix A

1 Estimating Storm Runoff Distribution on Ungauged Streams in Nova Scotia (Adamcyk and Langley, 1971).

Adamcyk and Langley (1971) developed equations for estimating the six-hour hydrograph peak, the time to peak, and the time from the peak to the end of runoff as presented as a function of basin characteristics.

2 Regional Flood Frequency Analysis for Mainland Nova Scotia Streams (MacLaren Atlantic Limited, 1980).

Several of the figures contain information relevant to the present study. Total annual precipitation is shown to vary from approximately 1200 mm to 1300 mm, with mean annul runoff from approximately 900 mm to 950 mm (MacLaren Atlantic Limited, 1980). Generally, the amount of snowfall was found to vary with topography, and proximity to the Atlantic Ocean and Gulf of St. Lawrence. Total annual snowfall was depicted as about 2000 mm in Antigonish to 2500 mm in interior of mainland Nova Scotia (away form the coasts), with median snow cover on March 31 being about 50 mm in the Antigonish area (MacLaren Atlantic Limited, 1980). It can be determined from the work done by MacLaren Atlantic Limited (1980) that surficial soil type should result in moderate to median runoff potential for most of the West River basin, with low to moderate runoff potential in the headwater area, but this also depends upon other factors such as development and antecedent moisture conditions.

3 Hydrometric Network Review Nova Scotia (Environment Canada and the Nova Scotia Department of the Environment, 1985)

In the mid 1980s, Environment Canada and the Nova Scotia Department of the Environment carried out a study to determine the adequacy and relevancy of hydrologic networks and data in Nova Scotia (Environment Canada and the Nova Scotia Department of the Environment, 1985). Statistical analyses were performed on surface water data to determine variance, skewness and trends in runoff. Correlations between annual and monthly mean discharges were also done to determine if relationships existed between stations, which confirmed the existence of three hydrologic zones as were previously defined by Inglewood (1970). These zones were Southwestern Nova Scotia, the Cape Breton Highlands, and Northeastern Nova Scotia excluding the Cape Breton Highlands (Environment Canada and the Nova Scotia Department of the Environment, 1985). The West River is in Zone 01D, draining to Northumberland Strait.

As part of the hydrometric review, computations of the mean annual daily discharge, the standard deviation (SD), the coefficient of variation (Cv), standard error as a percent of the mean, and the coefficient of skew (Cs) were performed. This was done for all longterm stations over the period of record to 1969 (year of the previous network review) and over the period of record to 1983. A general increase in the mean, SD and Cv were detected indicating an increase in annual runoff and variability of mean annual discharge. It was also observed that values of Cv varied between the three zones as proposed by Inglewood (1970), and it was speculated that this could be due to the effect of winter thaws on the snow cover (Environment Canada and the Nova Scotia Department of the Environment, 1985).

The hydrometric review report also contains a description of physiographic, geology, and climate of Nova Scotia, flow duration curves for selected stations, discussion of previous reports including Inglewood (1970), uncertainty functions for selected gauging stations, and information on groundwater and climate monitoring networks (Environment Canada and the Nova Scotia Department of the Environment, 1985).

4 Low Flow Characteristics of Nova Scotia (Water Resources Branch, 1986)

Environment Canada undertook a study to determine the characteristics of low flows in 33 natural-flow streams in Nova Scotia in order to provide information that could be used in the estimation of low flows within specific geographic areas (Water Resources Branch, 1986). Low flow data were input to the LOWFLOW, which was used to estimate the parameters to define the Gumbel III distribution, also known as the Weibull distribution. Of the 33 stations, 10 stations were on Cape Breton Island and five stations were in the eastern portion of peninsular Nova Scotia. Results were provided in the form of low flow frequency curves and tables of basic statistical information, such as the mean, standard deviation, and coefficient of variation (Water Resources Branch, 1986).