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APPENDIX F

TECHNICAL MEMORANDUM – 2010 HYDROTECHNICAL SUPPORT FOR MAJOR RIVER CROSSINGS

TECHNICAL MEMORANDUM

Date: August 4, 2010   **Project No.:** 093-81059

To: Project File   **Project:** Canada Chrome Railroad

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RE: 2010 HYDROTECHNICAL SUPPORT FOR MAJOR RIVER CROSSINGS

This memorandum summarizes the hydrotechnical work done to develop hydrologic and hydraulic design criteria and identify design considerations to support the feasibility study and preliminary design phases of the proposed Canada Chrome Railroad project. The hydrologic and hydraulic feasibility studies were done by a team of consultants including: TKDA, SRF Consulting Group, Inc. (SRF), Krech Ojard & Associates (KO), U.S. Army Corps of Engineers, Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (CRREL), and Golder Associates, Inc. (Golder). Golder and CRREL focused on hydrotechnical support for detailed assessments of the 10 largest river crossings[1] and provided general guidance that applies to all river and stream crossings along the proposed railroad alignment.

Preliminary assessments of the following were conducted for each major river crossing:

- Hydrology

- Hydraulics

- Ice Jam Potential

- Debris Jam Potential

- Scour, Erosion, and Bank Protection

The assessments conducted for the river crossings are described in the following sections along with general considerations pertaining to design.

1.0 DATA SOURCES

The following sources of data were used.

- LIDAR derived elevation data, 1 m resolution – project specific dataset.

- Orthomosaic aerial images, 0.2 m resolution – project specific dataset.

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- Digital Elevation Models (DEMs) 20- and 30-meter resolution – Ontario Ministry of Natural Resources

- Hydrography – Ontario Ministry of Natural Resources

- 250 K Topographic Maps – CanMatrix, Natural Resources Canada

- NHN Work Unit Limits – Natural Resources Canada

- Watershed boundaries – Ontario Ministry of Natural Resources

- Stream gauge data from Water Survey of Canada

- Temperature records (where available) – Environment Canada

- Photos (oblique taken from helicopter or from the ground) at the 10 major river crossing locations[1] showing presence or absence of ice scars

- Ice thickness and water depth measurements across 10 major river crossing locations, collected during geophysical investigations of the crossings completed by Golder[1]

- Geophysical investigations completed by Golder including ground penetrating radar and electrical resistivity imaging transects profiling depth to bedrock at the 10 major river crossing locations[1]

2.0   HYDROLOGIC ANALYSIS

The design storm selected for peak flood flow analysis is the 100-year recurrence interval flood event. The design storm was selected by discussions of the design team, and through review of standard of practice technical information. Smaller storm events were also included in the study to evaluate potential ice or debris impacts for structures where the design flow and corresponding flood levels are relatively low.

The preferred hydrologic method of estimating peak flows for a river crossing location is to perform a frequency analysis on long-term flow records at a nearby gauging station on the river of interest. This method is known as the Single Station Frequency Analysis (SSFA) Method. When gauge data is not available for a given river, the two types of methods that can be used to estimate peak flows are hydrologic model-based methods and regional frequency analysis methods. Hydrologic models were not used in this analysis because gauge flow data was not available at this phase of the project to develop a robust calibration of hydrodynamic models. Regional frequency analysis methods were used to estimate flows in ungauged basins.

Hydrologic characteristics of basins draining to each bridge crossing were determined by SRF and TKDA using geographic information system (GIS) and the various data sources listed in Section 1.

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2.1 Single Station Frequency Analysis (SSFA) Method

The most reliable and preferred peak flow estimation method applicable to the project area is Single Station Frequency Analysis (SSFA). SSFA utilizes the records of annual maximum floods at a gauging station to calculate the frequency distribution of peak instantaneous flow rates at the station. The ratio of peak instantaneous values to the mean annual value can be determined from the data. This analysis is typically used to provide the peak instantaneous flow rate values for a range of recurrence intervals. There are a number of assumptions associated with this approach, including:

- There is an adequate period of record (i.e. years of data) to characterize the frequency distribution. Typically 30 years of record would be necessary to have confidence in estimates of the 100-year peak flows;

- The upstream land use remains relatively unchanged over the period of record;

- The data available is of suitable quality and reliability as to be usable.

Depending on the location of the crossing site relative to the gauging station, the following options can be considered:

- The single station stream flow data can be used directly if the station is in close proximity to the crossing site;

- Interpolating the stream flow data between two stream flow gauging stations on the same stream by comparison of the contributing drainage areas; or

- Transposing data from a distant stream gauging station based on drainage area or from a stream with similar watershed characteristics (e.g., similar watershed area, slope, and degree of urbanization).

The main limitation in using the SSFA method is the quality of the stream flow data being relied upon. The SSFA method was used on all crossings where nearby stream flow records were available including:

- Attawapiskat River

- Albany River

- Ogoki River

- Little Current River

2.2 Regional Frequency Analysis Methods

Regional Frequency Analysis Methods estimate peak flow rate for a location based on frequency analysis of stream flow and precipitation records at known locations with similar characteristics within the same

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region.   The records for many stations are often integrated to provide a set of regression equations suitable for use within an entire region or subclass with similar hydrologic characteristics.   The two Regional Frequency Analysis Methods suitable for the study area used in this analysis were: Modified Index Flood Method and Northern Ontario Hydrology Method.

2.2.1   Modified Index Flood Method

The Modified Index Flood Method (MIFM) was developed from a regional frequency analysis of annual maximum peak flow rates to produce a statistical regression equation that can be used to estimate a 25-year runoff event. Peak flows of other recurrence intervals are estimated by applying a frequency factor to the 25-year value. The MIFM is intended for use with watersheds greater than or equal to 25 km^2. MIFM flow estimates may be applicable for watersheds between 5 km^2 and 25 km^2, but should be compared with estimates from at least one other method.

TKDA, SRF, and KO used the MIFM to estimate peak flows for all proposed railroad crossings locations to be used in the hydraulic modeling analysis.

2.2.2   Northern Ontario Hydrology Method

The Northern Ontario Hydrology Method (NOHM) was developed to determine peak flow rates for ungauged basins located in small and medium sized northern Ontario watersheds between 1 km^2 and 100 km^2. In small to medium watersheds, the storage in lakes, natural depressions and stream valleys can have a potentially significant attenuation effect on peak flows.   NOHM requires the following watershed parameters: watershed area; area of storage (lakes and wetlands); desired return period of flow event; and type of watershed outlet (normal or lake). This method is intended for watersheds located in the Canadian Shield.

TKDA, SRF, and KO used the NOHM to estimate peak flows for all proposed railroad crossings locations to be used in the hydraulic modeling analysis.

3.0   HYDRAULICS

Preliminary HEC RAS models were developed by KO, TKDA, and SRF for all crossing locations along the proposed alignment using the LIDAR data the results from the Hydrologic Analysis described in section 2. These models were used to estimate 100-year flood levels and flow velocities expected at the crossing locations.   The results of the hydraulic modeling analysis support the ice, debris, scour, and erosion assessments and ultimately the bridge design.

The following hydraulic design criteria were selected for bridge and culvert crossings:

- **Maximum Allowable Stage Increase at Bridges**: 0.3 meters, but is likely to be less given the physical characteristics (soil stability, height of embankment, etc).

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- **Maximum Allowable Stage Increase at Culverts**: 1.0 meter below the top of rail (TOR)

- **Freeboard**: minimum of 1.0 meter, based on the lowest member of the bridge section and the design flood.

4.0   ICE CONSIDERATIONS

In northern rivers, ice can significantly increase the stage associated with flow rates at a location. Stage increases due to the presence of ice are due primarily to two effects. First, an ice cover floats on the surface of the water, thereby blocking flow area equal to approximately 92% of the ice cover thickness. Second, the stationary cover or jam provides a second shear boundary and thus a source of flow resistance, similar to the bed and banks of the river. This shear boundary may be smoother than the bed and banks in the case of an ice cover or significantly rougher in the case of an ice jam. These combined effects of an ice cover or jam can increase the depth of flow required to carry a given discharge above that of open water conditions. For the same discharge, an ice cover or jam increases the flow depth from 25 to 100% depending on the slope of the river, roughness of the cover or jam, and width to depth ratio.

Analysis of the effects of ice covers or jams on the hydraulics of rivers is not straightforward. Many factors combine to determine whether flow conditions will result in a simple ice cover or evolve into an ice jam. While it would be easy to assume that the highest stage conditions will result from an ice jam associated with the 100-year return flow, the conditions usually never occur due to a variety of reasons. Peak discharge events are often associated with a large precipitation event or in northern regions associated with the annual snowmelt. Both of these conditions are typically associated with significant melting of the ice cover and depending on the rate of the snowmelt, the ice cover may be significantly deteriorated, resulting in less of an impact on stage. Ice covers generally form during low flow periods during the winter months at a resulting low stage level. These covers often breakup as discharges rise in the spring, resulting in the potential for ice jams. While ice jams can result in very significant stage increases, as the discharge continues to rise (due to melt) a point will be reached where the jam can no longer be retained in place and it fails. Upon failure, the stages will significantly reduce (due to the loss of the upper shear boundary). While the discharge at which jams fail is site-specific, some assumptions can be made as to the conditions for which failure is eminent. Visual inspections can provide information as to the likelihood of ice jamming. For example, a wide flat area with vegetation typically associated with slow flow rates (wetland areas) would not be expected to experience ice jamming. On the other hand, a steep reach which exhibits shoreline erosion, tight bendways or sudden expansions or contractions would be more likely to experience jamming. While photographic documentation of jams is rare, ice runs and jamming often leaves scars in the outer bark layer of trees along the river bank at the elevation of the ice run. This permanent information can be assessed as to the potential for jamming but also can give indications of the stages during the jamming events as well.

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For this analysis, the impacts of ice were qualitatively assessed at each major crossing based on a variety of available information including the visual documentation of the river (open conditions), presence of ice scars along the banks, and determinations of the likelihood of ice jamming and jam failure with increasing discharge. For some crossing locations, ice was considered to be an insignificant problem. These were generally wetland, low-slope reaches where significant storage exists upstream of the crossing. Ice jams would not likely form and rarer return period discharges would result in higher water levels. At other locations, the following process needs to be followed:

1. A single maximum ice cover thickness is determined based on the available temperature record. This ice cover thickness is added to the cross section for HEC-RAS modeling.

2. The HEC-RAS modeling is used to determine the stages associated with a 2-year return period flow. It's assumed that this flow rate would be similar to the bank full flow. The stage associated with this condition is the static ice cover stage. At flow rates higher than the bank full flow, the ice cover would become unattached from the bank; begin to breakup, and travel downstream, resulting in potential ice jamming.

3. The HEC-RAS model is then run in an ice jamming mode with increasing discharges (higher return periods) and the results assessed to determine the discharge at which the ice jam could no longer remain in place. The ice jamming mode of HEC-RAS performs a force balance on a floating jam (ice accumulation) in which the forces of gravity and shear of the water flow pushing downstream are balanced by the shear resistance at the banks and the internal strength of the ice accumulation. The balance of forces is achieved by the jam increasing in thickness (and thus increasing stage) with increased flow rates. As the flow continues to increase, however, a point is reached where the jam will lose support at the banks (typically when overbank flow becomes significant) and the jam can no longer remain in place and washes downstream. The discharge at which this occurs is site specific but can be determined from the output of the HEC-RAS model. HEC-RAS computed variables that assist in the determination of ice jam stability include velocity beneath the jam, open water width, amount of flow in the overbanks areas, and slope of the river reach.

5.0 DEBRIS CONSIDERATIONS

Debris affects river stages and (especially) bridge openings in a manner similar to ice covers and jams. In this situation, debris is defined as trees, brush, or logs that are mobilized during a range of low to high flows. Debris that accumulates on a bank, along the bed, or on a man-made structure in the channel can also include sediment. Debris is typically sourced from erosion of the bed and banks, or lifted off the bed and/or banks during the rising limb of a flood hydrograph. Typically debris accumulations and jams do not

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cover as extensive an area as ice jams, but can be much more persistent since they do not melt out during warmer weather, and can continue to accumulate in downstream reaches.

Similar to ice accumulations, debris impacts can be modeled with HEC-RAS using the routines created for floating ice jam accumulations. Variables that can be adjusted to simulate floating accumulations (whether debris or ice) include the thickness, area of coverage, roughness, maximum velocity on the underside of the accumulation, internal strength (friction angle) of the accumulation material, and specific gravity. HEC-RAS also includes some easy to apply methods for simulating debris accumulations on bridge piers in which only debris width and length are provided as input variables.

Debris considerations should be incorporated into the final design of bridge and culvert crossing, in order to maintain acceptable freeboard and/or provide for scour protection.

6.0   SCOUR, EROSION, AND BANK PROTECTION CONSIDERATIONS

Vertical scour and lateral bank erosion are addressed in the following discussion.

6.1   Scour

Scour assessments at proposed crossings should include consideration of total scour. Total scour is the sum of applicable scour and erosion mechanisms at a given location and relative to defined flow conditions. The flow conditions for the selected crossings will be as discussed in previous sections of this report. HEC-RAS modeling tools can be used to apply the calculated hydrologic conditions to site-specific crossing topographic and bathymetric geometries. Scour and erosion assessments should always include applicable geomorphic considerations. Factors of safety can be applied as needed to all or individual scour and erosion mechanisms to delineate risk, represent site conditions, or add conservativeness to the results, as needed. Total scour can include one or more combinations of the following scour components:

1. Reach-scale degradation and aggregation. Reach-scale issues can be assessed through review of the site fluvial geomorphic characteristics. The generally flat gradient of the northern Ontario project area reduces the potential for significant vertical or lateral changes in channel alignment, but may still produce governing changes in channel geometry and bed form. Assessment of governing geomorphic characteristics should be made in the final design phase of the project, and include review of available site specific geophysical investigations (i.e. bedrock versus alluvial sediments along the bed and banks) and bathymetric data, as well as site reconnaissance including site specific observations of channel and floodplain conditions.

2. General Scour. General scour is the most common overall scour assessment applied to most riverine projects. General scour typically includes assessment of overall streambed changes in

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elevation due targeted flow/flood conditions. General scour can be uniform or non-uniform. General scour can result from contraction (the confinement of the channel due to natural or man-made features) or sediment transport dynamics. Typical methods for assessing general scour include: hydrodynamic modeling (1D, 2D, or 3D, as needed), field measurements, regime equations (e.g. Neill, Blench, and Lacey (BOR, 1984)), critical velocity, and competent or limiting velocity.

3. Local Scour. Occurs at obstructions or abrupt changes in channel geometry or flow conditions where flows accelerate around, over, or under the obstruction. This is common at bridge piers, at debris accumulations (wood, logs, or even ice), abutments, embankments, and man-made obstructions in the channel. Local scour is often considered relative to both clear water and live-bed (i.e. entrained sediment) conditions. Factors affecting local scour can include: width of obstruction(s), projected length of obstruction(s), total length of obstruction(s), depth of flow(s), velocity, sediments, angle of approach of governing flows, shape of obstruction(s), shape of pier/support(s), bed geometry, debris type, etc. A typical critical local scour condition assessed for bridge crossings is pier scour and abutment scour. Additional consideration may be given to the outlet side of culvert crossings.

4. Bend Scour. Occurs along the outside of channel alignment changes (i.e. bends in the river) where water surface elevations super-elevate, the thalweg orients along the outside of the bend alignment, and/or sediment mobilization and deposition causes the channel alignment to move. These changes along the bend alignment are typically associated with secondary "eddie" or "vortex" currents that exacerbate the problem.

5. Bed form scour. Related to the bed conditions along the channel. Typically more applicable to sand and silt based systems where dune and antidune regimes develop. This may not be applicable in coarser grained and bedrock governed channels.

6. Low flow channel incisement. Occurs where geomorphic conditions modify the width-to-depth ratio of channel geometry. May result from modifications to the channel and floodplain from large scale gravel removal, or corresponding changes in channel geometry that result in headcut erosion (which moves in the upstream direction). Channel incisement is often associated with lateral channel migration. The generally low-gradient, shallow, and bedrock controlled morphology of the crossings in the project area most likely limits this type of erosion and scour hazard.

Total scour results should represent the geomorphic conditions at a given site. In general, the calculated total scour should be applied to the lowest point in the channel (i.e. the thalweg) during low-flow

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conditions. Lateral changes in the channel, where applicable, may also track vertical scour changes into overbank areas. Factors of safety should be applied where the identified risk is increased and requires a commensurate increased design effort, where there is uncertainty in the inputs to the analysis, or where the variability in channel conditions presents unforeseeable changes in channel conditions. Several technical references and methods are available that look at the identified total scour components. The use of each method is typically governed by available data. Experience and judgment is required in the selection of applicable erosion and scour mechanisms at each crossing, and the corresponding application and use of erosion and scour analysis methods. Final selection of the methods to be used to evaluate scour and erosion will be determined based on available information during the final design phase of the project.

6.2   Bank Protection

Hydrodynamic modeling results combined with site investigations (drilling, soils sampling/testing, geophysical investigations) and evaluation of geomorphic trends around the crossings will support determination of bank armoring protection measures, as needed. Bank erosion and scour can be connected, such that excessive scour can undermine and destabilize channel banks. The results from the scour evaluations (discussed previously) should be incorporated into the bank protection assessments. In areas where bridge abutments are raised above native ground, using imported fill materials, armoring of the fill surfaces will be needed to protect against erosion from inundation flood waters. The most common application of armoring that is expected is along channel banks and abutment fill areas that are within the active channel or can be inundated during the design flood event. Hydrodynamic modeling and standard of practice engineering methods can support determination of armoring materials. Typical materials may include riprap, precast concrete, soil improvements, geotextiles, or enhanced vegetation. Hydrodynamic modeling may also determine that bank protection is not required, or that bridge openings do not impact hydrodynamic conditions.

7.0   ADDITIONAL FINAL DESIGN CONSIDERATIONS

7.1   Bathymetric Data/Investigations

The preliminary HEC-RAS models for bridge and culvert crossings should be updated with available bathymetric and/or geophysical investigation data. This data was collected for selected major crossings, including: Stinger Lake, Esnagami River, Colpitts Creek, Little Colpitts Creek, Ogoki River South, Ogoki River North, Albany River, Wabassi River, Inlet to Fish Trap Lake, and Tributary to Muketei River. This information will be used to support final design studies at each crossing, and additional geophysical surveys may be needed at other crossings.

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7.2   Scour/Erosion/Bank Protection Considerations

Final design should use the general approach outlined above, and include review of the available geophysical and bathymetric investigation results to support determination of potential vertical limits of scour (i.e. around bridge piers) and the potential for erosion along channel banks (at or around crossings) and at bridge abutments. Armoring may be needed upstream and/or downstream of crossings outside of the bridge abutments to protect against erosion and/or scour. Potential scour and/or erosion hazards will be mitigated in final design, by modifying bridge support configurations and/or providing bank and/or bed armoring. Mitigation measures addressing potential scour and erosion hazards will need to be reviewed on a site-by-site basis, considering the overall hydrologic, hydraulic, fluvial geomorphic, sediment transport, and proposed crossing parameters.

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