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November 17, 2006

Morrison Hershfield
235 Yorkland Boulevard, Suite 600
Toronto, Ontario M2J 1T1

Attention: **Mr. Edward Li**

Re: **Hydraulic Analysis of Preferred Preliminary Bridge Replacement Design, Argyle Street Bridge, Caledonia, Ontario**
Burnside File No. MB02 2588.410

Dear Mr. Li,

R. J. Burnside & Associates Limited (Burnside) has been retained by Morrison Hershfield (MH) to carry out Hydraulic Analysis for the preferred Preliminary Bridge Replacement Design for the Argyle Street Bridge in Caledonia, Ontario. This letter report summarizes the data inputs, methodologies used and results of the analysis that has been carried out.

1.0 Background Data

Engineering drawings of the bridge for existing, proposed and construction staging conditions were prepared by MH and provided to Burnside as base information for completing the hydraulic analysis.

Background information on flood flows for various return periods, flood lines in the vicinity of the existing Bridge and a copy of the most current version of the Grand River HEC-RAS hydraulic model were obtained from the Grand River Conservation Authority. Daily Grand River flow data was obtained from HYDAT software, as directed by staff of the GRCA.

2.0 Design Criteria and Guidelines

Design Criteria used in establishing the appropriateness of the proposed bridge design from a hydraulic capacity perspective includes the following:

- The proposed bridge should provide at least 1.0 metre of freeboard between the 100 year storm event water level and the bridge soffit;

- The proposed bridge should not increase the upstream surface water levels during the regulatory event, in this case the Regional Storm; and,
- A minimum of 2.0 metres of clearance should be provided between the bridge soffit and the normal summer water levels in the Grand River. Normal summer time flow rate was provided by the GRCA as 30 m^3/s, which corresponds to a water elevation at the bridge of approximately 185.3 metres.

In addition to the proposed versus existing comparative analyses, MH also wishes to understand the impact of the proposed construction activities (staging) on flood line elevations and in particular how they relate to their temporary in-stream works. As such, the analysis also includes determining (a) the return period flows during the proposed in-stream construction window, and (b) water levels at the bridge and upstream that would result from various storm event flows occurring while the construction access is in the river. For the purposes of this analysis, the height of the construction access causeway has been set at 0.6 metres (as suggested by MH) above the construction-period (seasonal) 2-year return event flow.

3.0 Description of Hydraulic Analysis Methodologies

The HEC-RAS hydraulic analysis is based on the existing bridge replacement alternative provided by Morrison Hershfield (Drawing no's. 1, SK-1 and SK-ST1). The following four scenarios were modelled to assess flow conditions (water levels and velocities) in the waterway for a variety of flow frequency events:

i. Existing conditions
ii. 80m causeway/coffer dam with 10 peirs (2 new and 8 existing) and temporary lower crank beam below existing deck [stage 1a]*
iii. 80m causeway/coffer dam with 12 peirs (4 new and 8 existing) and temporary lower crank beam below existing deck [stage 1b]*
iv. Final conditions with 4 new peirs and higher bridge deck

[*Causeway/coffer dam will cover about 80m of river cross-section. Once these works are no longer needed, these will be removed and installed on the other half of the cross-section.]

For the construction staging scenarios that involve working in the Grand River waterway, a hydrological analysis was required to estimate flood flows that should be representative of the construction period, i.e. from July to December (summer and fall months). It is worth mentioning that Grand River is highly regulated with seven reservoirs that control floods and maintain minimum flow in the system.

The existing HEC-RAS model, as provided by the GRCA, includes flood flows for various return frequencies (2 yr through Regional events), which are based on maximum annual flows. These flows are summarized in Table 1. In order to review appropriate height for in-flow staging areas and to review anticipated flows during the construction period, MH also requested that expected return period flood flows during the construction time frame also be reviewed. Seasonal return frequency flows (i.e. based on data from July to December) were requested from the GRCA, but these were not available. Therefore, as suggested by GRCA staff, daily flow records from 66 years at the Brantford gauge was extracted from Environment Canada HYDAT information. This data was processed for missing data and other inconsistencies and then analysed to determine 2 yr through 100 yr seasonal return period flows for July to December. As the Brantford gauge is located upstream of the bridge, representative flows at the bridge were derived by two different methods. The first method involved a simple pro-rating factor, based on drainage areas, that was applied to transpose flows downstream; while in the second method, Brantford gauge flows were added to Fairchild creek flows to develop flow data that should be reflective of flows at the bridge. The first method yielded more conservative values and thus was adopted for further analysis. The calculated July to December seasonal return flows are summarized below in Table 1, along with calculated annual flows using the same methodology and the HYDAT data.

Review of the daily flow record indicated one instant where flow exceeded 980 m^3/s during the period from July to December. This is the 2-year full-year return period flow reported in the GRCA HEC-RAS modelling. The average flow during this July to December seasonal period ranges from 80 to 195 m^3/s, with the highest being in December.

Table 1: Summary of Return Period Flows at the Site

Return Period (years)	GRCA HEC-RAS Model Flows (m^3/s)	Pro-rated Annual Based Flows from HYDAT (m^3/s)	Maximum July to December Flows (m^3/s)
2	980	673	250
5	1353	952	429
10	1620	1137	544
20	1863	1315	655
50	2158	1545	798
100	2357	1717	905

As the table shows there is a discrepancy between the GRCA and HYDAT values. At the time of preparing this report, there had not been an opportunity to discuss this difference in flows with the GRCA. Confirmation of calculated seasonal flow values and their use in calculating risk of temporary in-stream works should be carried out with the GRCA and must be undertaken at the detailed design stage of this project.

The results may lead to modifying the construction phasing methodology and the implementation of the causeway/coffer dam installation. It is worth mentioning that the Grand River is highly regulated with seven reservoirs that control floods and maintain minimum flow in the system. This may possibly be a reason for differences in model flows and calculated flows.

4.0 Results

The hydraulic analysis was undertaken for the four scenarios to estimate their hydraulic effects for different flow events in terms of flood elevations and velocities. The following sections describe the results of the analysis.

4.1 Existing Bridge Hydraulics

The existing Argyle Street Bridge has 8 piers with a total span of about 200 metres. The soffit elevation at the centre of the span is 190.60 m. Under existing conditions, the upstream water levels for the 100-year and regional storms are 190.03 and 190.25 metres respectively (see Table 2). The water levels and associated velocities for different flow events are shown in the following table. A full summary of water elevations and velocities at the bridge section and three upstream sections is attached to the back of this report.

Table 2: Water Levels at Upstream of Bridge

Flow Event	Peak Flow (m^3/s)	Water Level (m)	Freeboard from Soffit (m)	Mean Velocity (m/s)
Regional	2,562	190.25	0.35	2.64
100-yr Ann. Max	2,357	190.03	0.57	2.52
2-yr Ann. Max.	980	188.15	2.45	1.64
2-yr Max. Jul – Dec.	250	186.34	4.26	0.96

As shown in Table 2, the existing bridge does not provide a minimum of 1.0 m of freeboard from the bridge soffit during a 100 yr event. The existing bridge opening has a flow area of about 1,013m^2. The proposed bridge opening should be modified to ensure the 1.0 m of freeboard is met. Floodline elevations and velocities will be used as the point of comparison to assess the suitability of the proposed bridge and construction phasing scenarios.

4.2 Proposed Replacement Bridge Hydraulics

The proposed replacement for the Argyle Street Bridge will be a wider 5-span structure with 4 piers and a centre soffit raised by 1.50 metres (centre soffit elevation of 192.10m). The elevation of the ends of the bridge will match the existing bridge end elevations at 190.20m. This will improve hydraulic conveyance through the bridge opening and, thereby, lower the energy or water levels at the bridge and upstream during high flow events. The hydraulic analysis results for the 100-year flood and Regional event are shown in Table 3. A full summary of water elevations and velocities at the bridge section and three upstream sections is attached to the back of this report.

Table 3: Water Levels at Bridge Upstream for the Extreme Events

Flow Event	Peak Flow (m^3/s)	Water level (m)	Mean Velocity (m/s)	Freeboard at centre (m)	Freeboard at ends (m)
Regional event	2,562	190.24	2.26	1.86	-0.04
100-year	2,357	190.03	2.15	2.07	0.17

As mentioned earlier, the existing water level under the 100-year storm is 190.03 metres and 190.25 metres under the regulatory flood with corresponding velocities of 2.53 and 2.64 m/s. It is evident that the water level reduces marginally during the regulatory event. Also, the reduction of piers in the waterway under the new hydraulic structure causes flow velocities to decrease. Because of the increase of the centre soffit elevation, the desired minimum 100-year freeboard of 1.0 m is also achieved. The full summary table attached to the back also shows the upstream water levels do not increase, and in some cases decrease with the new bridge configuration.

In summary, the proposed bridge configuration should not result in an increase in upstream flood elevations. Criteria of 1.0m of freeboard during a 100-year event and minimum of 2.0 m of freeboard during normal summer flows are also met.

4.3 Construction Staging Hydraulics

As discussed above, the ultimate proposed bridge configuration will not negatively impact floodline elevations or velocities compared to the existing structure. However, in order to carry out the proposed construction, staging activities will require the temporary lowering of the soffit elevation (by means of a cranked beam installation), as well as the construction of temporary construction access causeways and cofferdams for pier installation. Thus, during this construction staging, the hydraulic capacity beneath the bridge will be significantly reduced. Because of this, the timing of construction activities will need to be set so that any causeway / cofferdams are in the river only during periods of seasonal lower flows.

MH has suggested that, for hydraulic analysis purposes, the top of the causeway structure be set at 0.6 metres above the river's 'normal water level' The average daily flow over the record period, using the available HYDAT data, was approximately $172m^3/s$. For the purposes of this analysis, the seasonal Q2 (2-yr maximum flow from July to December) of 250 m^3/s was used as the basis for establishing a top of causeway/cofferdam structure, as it offers a more relevant basis and is higher (or more conservative) than using the normal or average daily flow. Thus the causeway/coffer dam was modelled with a top of elevation of 187.00 metres; approximately 0.6 m above the water levels experienced during the seasonal Q2 event.

Construction scheduling information provided by MH indicates that the construction timing windows for causeway/cofferdam installation on the Grand River will be between July and October. As discussed earlier, the Grand River is at its lowest flows during this period, and flows tend to increase in the fall period. Since there are some extreme events associated with the fall months, and given the tendency for delays in construction projects, it was considered that the hydraulic analysis of the temporary works be based on a seasonal period from July to December; a period somewhat longer than the construction period. Using this approach, and the HYDAT data, the top of the causeway/coffer dam was modelled at 187.00 metres, which is 0.6 metres above the Q2 (July to December) water level. Table 4 presents results of the hydraulic analysis for the two construction staging scenarios (ii) and (iii) wherein the low flow area is reduced by the construction of the temporary causeway/coffer dam and cranked beam from the top of bridge. The full summary table attached to the back also shows the upstream water levels do not increase, and in some cases decrease with the new bridge configuration.

Table 4: Variation of Water Levels and Velocities with Bridge Opening

	Stage 1a - 2-yr Ann. Max. (Jul–Dec)	Stage 1b - 2-yr Ann. Max. (Jul–Dec)
Bridge Opening (m^2)	730	540
Water level (m)	186.35	186.40
Mean velocity (m/s)	1.65	2.1

In stage (ii), the flow area through the bridge is reduced by 28% while in stage (iii) the reduction is about 47%. The analysis suggests that, for the seasonal Q2 (July to December), the causeway/coffer dam should not be overtopped. It will be extremely important for the contractor to closely monitor river flows throughout the duration of the construction works and to have an established evacuation plan in place for periods when flows are expected to increase.

It is also extremely important to note that there is the risk at any time of the year that a major flow event could occur. In such an event, it is likely that water levels will exceed the 187.00 m elevation. Analyses where run to determine the impacts of flood events associated with annual maximum return period flows (Q2 to Q regulatory), as well as lower frequency seasonal events based on the HYDAT data, when the proposed causeway/cofferdams where in place. The results of these analyses are summarized in the full summary table attached to the back of this report. Results indicate that if a major event (Regional or 100-year) were to occur when the proposed temporary works were installed in the river, there would be significant impacts to flooding at the bridge and upstream. Because the flow area is drastically reduced, flood elevations would increase by 0.85m at the bridge in a regional event, compared to the existing bridge structure. Flood elevations upstream could increase by as much as 0.97m in the same event. Flood elevations that would occur from a 100-year event would surpass the Regional flood elevations experienced with the existing structure in place. As such, it will be very important for a plan to be put in place to either remove the temporary access if a large event is forecast, or for alternate staging methodologies with less hydraulic impact to be developed during detailed design.

4.4 Summary of Hydraulic Analysis

The following provides a summary of the analyses completed for the existing bridge, proposed bridge and construction staging scenarios:

- The existing bridge soffit is too low to meet the desired criteria of 1.0m freeboard during a 100-year event;
- The proposed bridge centre soffit elevation is raised by 1.5m and the bridge uses fewer piers, such that the total flow area beneath the structure is increased. Accordingly, water elevations and velocities at the bridge and upstream are either maintained or decreased compared to the existing bridge. All desired hydraulic criteria listed in section 2.0 of this report are met.
- The construction staging scenarios, especially the 2nd stage, will drastically reduce the flow capacity of the bridge. As such, if the currently proposed staging methodology is used, all works should be limited to the driest months of the year (July to October). River flows would need to be closely monitored at all times and evacuation and causeway removal plans should be in place to address flood events that may overtop the causeways and/or result in increased upstream flooding. The modelled causeway/cofferdam height of 187.0m is based on protecting against the calculated seasonal Q2 event with 0.6m of freeboard. This should be re-evaluated at detailed design as well as by the contractor to meet the level of risk that the design engineers and the contractor are willing to assume.

5.0 Additional Work Required at Detailed Design Stage

The present hydraulic analysis is based on the cross-sectional information embedded in the model. The analysis should be refined when the final configuration of the replacement bridge is completed during the detailed design. There will be a need to take new cross-sections upstream and downstream due to the change in bridge width (in the direction of flow). This will also confirm the cross-sectional data currently used in the GRCA model (existing bridge is located between cross-sections having inter-distance of 14.20 metres whereas the new structure width is 20±1m). Other required details to be included in the updated model would be any updated designs to construction accesses, access removal plans, pile caps, abutments, and regulated and deregulated hydrologic analysis for summer and fall flows.

In addition, and as discussed earlier, the return frequency flows should be discussed further with the GRCA to reconcile the differences in values already discussed. The project proponent and the GRCA should also negotiate and agree on the return frequency in establishing the level of protection required for the temporary works.

Yours truly,

R. J. Burnside & Associates Limited

Jeff Boyd, P.Eng., M.B.A.   Zak Zakeria, M.Sc., E.I.T.

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