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Executive Summary

A need to update the previous flood line delineation analyses was identified by the HRM. This need arose from the emergence of updated information and tools of much better quality (topography, flow and water level, rainfall, hydrologic and hydraulic computer models), as well as research on climate change, and pressure from the business community.

This study has assessed the hydrology and hydraulic regime of the Sackville River and the Little Sackville River, as well as their respective watersheds, in order to produce floodplain maps for various flood scenarios. Flood risks were evaluated based on a calibrated hydrologic and hydraulic model using PCSWMM, and an ice jam hydraulic model using HEC-RAS. Model calibration and validation for the PCSWMM model was carried out for flood events corresponding to each of the four seasons, and for each of the two rivers. Design flood scenarios included variations in seasonal conditions, rainfall conditions under climate change, sea level conditions under climate change, development conditions and ice conditions for various rainfall events and sea level events. The resulting flood lines delineated for this study include seasonal changes, historical design storm, existing climate, existing and future development, various scenarios of climate change for existing and future development, ice jam analysis and previous flood line comparison. Mapping of the Phase I river flow frequency analysis results is presented as well.

The thorough analysis presented in this report was carried out to support the flood extents produced by the hydrologic and hydraulic models. The flood extents may be incorporated into future planning documents, which warrants this thorough analysis. Included in this assessment was also an in-depth analysis of climate change impacts on rainfall and sea levels. Since climate change is to be considered in planning documents, it was essential to use the best science and tools available to evaluate those effects. Other significant inputs to this assessment included a radar-rainfall analysis to improve the model calibration, an ice jam analysis and model calibration and validation for each season in the year for both rivers.

The Request for Proposal (RFP) required a recommendation for the selection of a Base Flood. This was defined by HRM as a pair of flood lines, for the floodway (1 in 20 year) and floodway fringe (1 in 100 year), for planning and regulatory purposes. Since the scope of this study does not include any stakeholder consultation, assessment of vulnerability of floodplain infrastructure, land uses and services, nor any review of existing and future planning challenges and opportunities, the current recommendation is strictly related to river hydrodynamics and the current state of climate change science.

In this respect, CBCL agrees with following HRM's proposition, which is to select the most conservative model result to ensure that known risks to public safety are not being ignored.

This means that the future 1 in 20 year and 1 in 100 year flood lines in worst case climate conditions is recommended, which, in this instance, includes the following characteristics:

- Fall seasonal watershed characteristics for the Little Sackville River;
- Winter seasonal watershed characteristics for the Sackville River;
- 24-hour duration design storm event for the Little Sackville River;
- 48-hour duration design storm event for the Sackville River;
- Future development conditions for both watersheds (as known at the time of this study by HRM);

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- Climate change conditions for the Western University IDF-CC Tool upper bound result for the 2070-2099 period; and,
- 1 in 20 year and 1 in 100 Year return periods.

The first result of interest is the comparison with the previously generated flood lines. A comparison is made between the 1 in 100 year flood lines from the 1980's regulated floodplain width, the Porter Dillon study from 1999 and the current modelling results. It is clear that the use of the lidar data and computer mapping techniques improved the resolution and consistency of the model results (previous results were drawn by hand). Beyond this, hydrotechnical modelling also shows the flow regime in steep sections allowing the river width to narrow (for example, around the Downsview Mall), which was not identified in previous assessments. The other prominent difference is in the downstream areas of the Highway 101 and the Bedford Place Mall. The updated model results show significantly larger flood extents, where both locations are under extensive flooding during the 1 in 100 year event. Those changes are estimated to result more from the improved quality of calibration, hydrodynamic modelling and surface topographical data, rather than the increased extent of the flow monitoring record.

Other findings from this analysis include the identification of factors that lead to the flooding extents generated by the models. The analysis of structure constrictions only identified four structures that create notable impediments to the passage of water. Those structures are the Beaver Bank Cross Road, Beaver Bank Road and Sackville Drive structures along the Little Sackville River and the Lucasville Road structure along the Sackville River. Other than those structures, there are few anthropogenic impacts to the natural shape of the river channel, other than river diversions to circumvent development. This is a notable finding, because it demonstrates that flooding outside of the river channel (i.e. in the floodplain) is a natural phenomenon. Natural rivers create over time a natural channel whose size is reflective of average river flows. Flows above average values carve a natural floodplain in the landscape. The majority of floodplain extents in Nova Scotia rivers were created during the melting of the last ice age glaciers, approximately 10,000 years ago. These are natural floodplains, which rivers occupy in higher than average flows. The model results show that the current 1 in 100 year peak flood extents occupy a large portion of this natural "ice melt" floodplain. Notably, the model results also indicate that events of a greater magnitude, including the 1 in 500 year event, the Probable Maximum Precipitation (PMP) or future events influenced by development and climate change lead to increased floodplain width (as expected), but only by a small relative amount. This means that high flows will regularly fill the floodplain, but that extremely high flows will still stay within this main floodplain. It is important to note this because it means that the floodplain is necessary for the conveyance of high flows. Development within the floodplain will unavoidably be at risk of flooding, and any restriction of this floodplain will lead to higher upstream water levels. Notable development in the floodplain includes the road crossings noted above, the Downsview Mall, the development around Sackville Cross Road, the Contessa Ct. and Sami Dr. residential developments, the Bedford Place Mall and adjacent residential development. The most notable infrastructure that alters the floodplain is the Highway 101 crossing and its interchange with Highway 102. All the above areas are at risk of flooding because they lie within the natural floodplain. Their impacts on flood levels seem to be limited, but this has not been confirmed by modelling a scenario where this development does not exist.

The assessment of seasonal effects on flood risks also yielded interesting results. The Little Sackville River, being more urbanized, did not show notable seasonal variations in flood elevations. However, the Sackville River showed high sensitivity to seasonal changes, with

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close to a metre of difference in water levels, downstream of its confluence with the Little Sackville River. Development projections showed little influence, with an increase in the order of 100 mm in the downstream end of the Sackville River. Tidal effects, with and without climate change, were shown by the model to be limited to just upstream of the Bedford Highway.

The hydrologic model was calibrated on historic flow records. The results of the model are therefore consistent with the historical peak flows (e.g. the 1 in 100 year peak flow is calculated in the model to be a seasonal average of 38.5 m^3/s in the Little Sackville River, which compares to 26.3 m^3/s from the flow gauging data and 109.75 m^3/s in the Sackville River, which compares with 115 m^3/s estimated directly from the flow gauging data). Compared to the historical storm of March 2003, the water level results are slightly higher throughout the river system, which is consistent with the finding that the March 2003 event was less significant than a 1 in 100 year event.

Results of modelling rainfall impacted by climate change were also generated. It was found that the large number of existing climate change models, combined with the various methods of transformation of the results into rainfall amounts, produced a wide range of results, with the highest rainfall amount calculated at 283.9 mm, a 70% increase compared to the existing 1 in 100 year rainfall amount (166.7 mm). Interestingly, while the water levels increased accordingly, the floodplain width did not significantly widen. This is mostly a result of the existing floodplain topography in which the floodplain edges have higher slopes, resulting in a small change of width when water levels increase. The 1 in 500 year event results showed larger flooding extents than the 1 in 100 year event, but again, to a limited extent. Since the total rainfall amount in 24 hours is 199 mm for the 1 in 500 year event, it is only marginally higher than the 1 in 100 year total rainfall amount (166.7 mm), and notably lower than the climate change amount (283.9 mm). Results are therefore much closer to the 1 in 100 year event than the worst case climate change scenario.

A discussion of potential flood mitigation options considers the benefits and challenges associated with each potential measure. Although this assessment did not investigate in detail, nor model, any flood mitigation option, certain high level aspects can be drawn from the results. The flood line delineation showed that climate change impacts clearly have the potential to increase flooding risks and should be considered in any future planning decision. The planning regulations will be central to managing future development and it is recommended that they include language on setback limits, runoff control, flood proofing or limited uses in floodplain areas. Designating environmentally sensitive areas (e.g. Watercourse Greenbelt zoning in East Hants) is also recommended to prevent future development in water storage and undeveloped floodplain areas.

While the upper reaches of the Sackville River are mainly undeveloped, its lower reaches, and most of the Little Sackville River, are quite highly urbanized, which is both increasing river flows as well as creating vulnerabilities. The following list of factors have contributed to the prioritized recommendations noted below.

- Risks associated with climate change;
- Increased interest in sustainability;
- Increased awareness of liability;
- Increasing costs of maintenance, and
- General reduction in funding for infrastructure projects

Recommendations have been generally oriented towards more sustainable, low maintenance, more nature-oriented approaches, which provide not only solutions to

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flooding risks, but also additional advantages in terms of erosion protection, water quality improvements and overall aesthetics and protection/restoration of the natural character of the rivers. This is consistent with the Sackville Greenway Plan, the Halifax Regional Plan and the Halifax Green Network Plan (Greenbelting and Open Space Plan).

Recommendations for flood mitigation, beyond adopting the floodlines in this report into planning regulations, are the following:

1. **Stormwater Infiltration - Best Management Practices (BMPs) and Low Impact Development (LID):**
   The least intrusive and most cost-effective flood mitigation option is to implement stormwater infiltration measures (LID and BMPs). It is recommended that such measures be enforced for all future development (more effective than detention ponds) through planning regulations and during resurfacing or repair works. BMPs and LID can have a very low direct cost but make a clear impact in flood reduction, in a manner that mimics natural processes;
2. **Increasing channel capacity through river restoration**:
   Other recommended approaches include conducting river restoration to increase capacity and storage in river sections that have been channelized. Significant ecosystem benefits are also achieved;
3. **Purchasing properties at risk**:
   The impacted individuals are now permanently safe, properties at risk can be restored to the natural floodplain, upstream flooding risks can be reduced, there is no further maintenance cost or residual risk, and the riverfront area can now be enhanced for public enjoyment. The challenges are its cost and resistance from property owners. Where not yet developed, purchasing floodplain lands can ensure their protection in the future;
4. **Flood Protection Infrastructure**:
   Options such as upgrading bridge structures, building berms, or raising the level of the land or homes, should only be used after the above options have been exhausted. They will be expensive, require maintenance, will move the problem downstream and will place public safety at increased risk for events greater than the design event.

In all cases, stakeholder consultations and modelling should be carried out to identify the best compromise between protecting vulnerabilities, overall stakeholder needs, ecosystem protection and costs. The creation of a dedicated floodplain committee (possibly cross-municipal to include the Municipality of East Hants) with regular meetings can streamline this process.

Overall, this study has updated the current state of knowledge on rainfall, hydrologic (including seasonal) characteristics, river flow responses, impacts of structures and ice jams, mechanisms leading to flooding, potential climate change impacts and potential flood mitigation options. This study has brought very detailed data sets of high resolution and quality, combined with state-of-the-art modelling and analysis to inform the results and recommendations presented.

Recommendations to improve this analysis in the future would include conducting further flow gauging in various areas of the watershed, evaluating in more detail ground infiltration and exfiltration characteristics, being cognizant of the latest climate change research as it progresses, and trying to collect as much calibration data (water levels) as possible in the rivers during flood events.

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In terms of recommended next steps for the HRM, the first goal of this study is to provide information to support an update to the planning regulations. An essential step, as noted by the HRM, is to make every effort to communicate the results and implications of this study and planning regulation to the public and all affected stakeholders, which is best achieved by using a wide range of approaches. Communication of flooding risks and emergency procedures, as well as flood proofing techniques, is also very valuable to help residents understand and deal with flooding risks. Warning systems, including flood forecasting and warning, can be very valuable tools to increase public safety. In terms of flood mitigation options, next steps will need to include conducting more detailed analyses and modelling of potential options. This can be done in parallel with an assessment of vulnerabilities along the river system, conducted through consultation with each of the relevant stakeholders. Vulnerabilities for land use, infrastructure and services can be obtained from stakeholders. Together with vulnerabilities in the management of emergency procedures (e.g. ensuring reliable communications or access to emergency services), these can be ranked by priority to define flood protection goals. How well each flood mitigation measures addresses each vulnerability can then be used to evaluate the efficiency of each flood protection measure.

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