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Hydrodynamic Modelling of Lake Ontario for Flood Resilience

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EXTENDED ABSTRACT

1 INTRODUCTION AND MOTIVATION

Lake Ontario's highly urbanized shoreline is exposed to large seasonal-interannual lake-level variability and episodic high-water events that can stress coastal infrastructure and complicate shoreline risk management. Recent extreme seasons (International Joint Commission, 2020) underscored the need for long, physically based reconstructions of water levels that are both quantitatively evaluated and suitable for flood-resilience applications. This study develops and evaluates a long-term, depth-averaged hydrodynamic hindcast of Lake Ontario using TELEMAC-2D over 1992-2021 (Ata et al., 2014), forced by observed boundary conditions and reanalysis-based atmospheric drivers. The scientific contribution is to quantify, in a consistent modelling framework, how well a single optimized 2D configuration can reproduce multi-decadal water-level variability and historical high-water extremes that are directly relevant to flood-resilience planning.

2 MODEL SETUP AND FORCING

TELEMAC-2D solves the depth-averaged Saint-Venant (shallow-water) equations using an unstructured finite-element mesh, which enables targeted refinement along complex shorelines and boundary corridors while remaining computationally feasible at the lake scale.

The model is forced with (i) daily Niagara River discharge at Queenston (upstream inflow), (ii) prescribed downstream water levels at the St. Lawrence outlet near Brockville, and (iii) hourly wind forcing from ERA5 reanalysis (Hersbach et al., 2020). A wetting-drying scheme is activated in shallow nearshore areas to represent exposure/inundation dynamics; evaluation focuses on lake-wide water-level skill at the gauge network.

2.1 Mesh sensitivity, scenario definition, and calibration approach

Mesh sensitivity was first examined using three baseline meshes coarse (52,243 nodes), medium (115,866 nodes), and finest (234,474 nodes) under consistent forcing and the same calibration window.

To refine the accuracy cost trade-off beyond the baseline three meshes, six additional candidate meshes (Scenarios 4-9) were generated between the medium and finest grids by redistributing resolution primarily in the Niagara inflow and St. Lawrence outflow corridors (Table 1). Screening was based on station-based performance metrics (RMSE, R^2, and Nash–Sutcliffe Efficiency) computed against observed water levels at five stations (Kingston, Cobourg, Toronto, Burlington, Port Weller) during the 2021 calibration period, together with numerical robustness (stable convergence) and feasibility for multi-decadal simulation.

Scenario 7 (125,109 nodes) was selected for the long hindcast because it provided a defensible balance between skill and runtime. The final mesh applies targeted refinement consistent with the basin physics: ~75 m resolution near the Niagara inflow, 225-675 m transition bands, ~180 m near the St. Lawrence outflow with a 450 m transition, and ~945 m in the lake interior.

3 VALIDATION RESULTS (1992–2021) AND EXTREME-EVENT PERFORMANCE

Across 1992-2021, the calibrated model reproduces observed water levels at the five validation stations with strong overall agreement. Burlington is used here as an illustrative example: daily simulated versus observed levels show high correspondence, with $R^2 = 0.89$, RMSE = 0.10 m, and Nash-Sutcliffe = 0.89 (Moriasi et al., 2007), indicating that the model captures the dominant variance in observed water-level variability over the full 30-year period at this station. For flood-relevant extremes, event-scale agreement was evaluated for the high-water seasons of 2017 and 2019 at Burlington. In 2017, the simulation reproduces the observed high-water plateau with a simulated peak of approximately 75.9-76.0 m and an event RMSE of 0.11 m, supporting close agreement in both magnitude and hydrograph evolution during the extreme season. The 2019 high-water season shows similarly strong correspondence, with event RMSE = 0.11 m, indicating that the calibrated configuration remains performant during a second major extreme period.

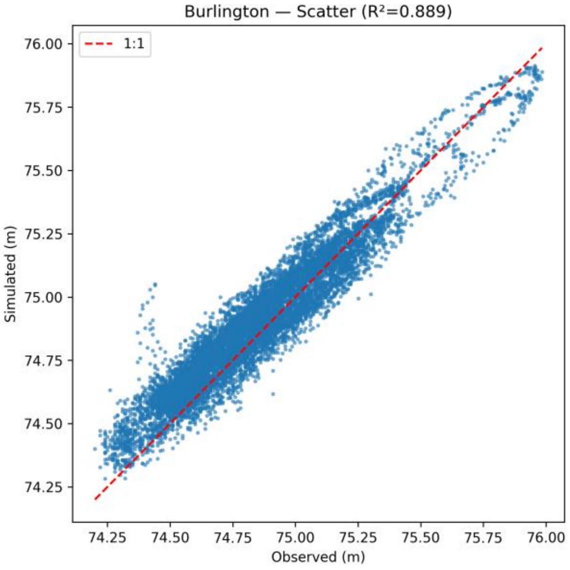

Figure 1: Daily simulated versus observed water levels at Burlington for 1992-2021.

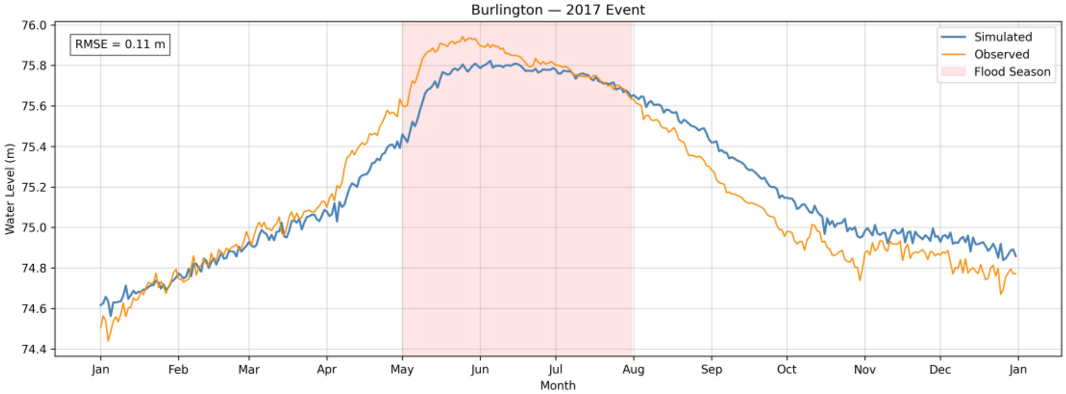

Figure 2: Burlington 2017 high-water season hydrograph: observed and modelled daily water levels (time series comparison).

4 CONCLUSIONS AND FLOOD-MANAGEMENT IMPLICATIONS

This study demonstrates a practical workflow for producing a quantitatively evaluated, multi-decadal Lake Ontario hindcast using TELEMAC-2D, and for identifying an accuracy–cost mesh choice suitable for long simulations.

The mesh sensitivity and scenario screening indicate that a sub-kilometre-scale unstructured mesh (Scenario 7) provides a defensible balance between station-based skill and computational cost for multi-decadal application. At Burlington (illustrative example), the configuration maintains low error during major high-water seasons (2017 and 2019), supporting its use for analysing historical extremes central to flood-risk management.

From a flood-resilience perspective, the validated hindcast provides a physically based reconstruction of historical lake-level variability and extremes that can support shoreline risk communication, resilience benchmarking, and evaluation of adaptation strategies that require credible historical water-level behaviour. The framework is suitable for extension to future analyses (e.g., scenario forcing, climate-change impact assessment, and hydrodynamic baselines for compound flooding and statistical risk assessment). These results provide a defensible hydrodynamic baseline for subsequent compound-event and probabilistic flood-risk analyses along the Lake Ontario shoreline.

5 REFERENCES

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., … Thépaut, J.-N. (2020). The ERA5 global reanalysis. Quarterly Journal of the Royal Meteorological Society, 146(730), 1999–2049. https://doi.org/10.1002/qj.3803

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885–900. https://doi.org/10.13031/2013.23153

International Joint Commission. (2020, January 23). Background paper answers key questions on 2019 Lake Ontario and St. Lawrence River flooding**.** https://ijc.org/en/loslrb/background-paper-answers-key-questions-2019-lake-ontario-and-st-lawrence-river-flooding

Ata, R., Goeury, C., & Hervouet, J.-M. (2014). *TELEMAC modelling system: 2D hydrodynamics, TELEMAC-2D software (Release 7.0): User manual*. EDF R&D. https://www.opentelemac.org/downloads/MANUALS/TELEMAC-2D/telemac-2d_user_manual_en_v7p0.pdf