Supplement of

InundatEd-v1.0: a height above nearest drainage (HAND)-based flood risk modeling system using a discrete global grid system

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Supplementary Discussion

Section S1: InundatEd and Damage Computation

As part of the features of the InundatEd web application, and to contextualize the modelled inundation depths, FEMA’s Hazus Depth-Damage functions were applied to the simulated flood depths via the R package Hazus (https://www.fema.gov/hazus) (Goteti, 2014). Using the Hazus package, estimated percentage losses can be generated for model output inundation depths at individual locations specified by the user. Furthermore, the Hazus loss percentages are contingent on building-specific properties, offering a built-in variety of building types, descriptions, and situations (e.g., fresh water vs. salt water) to tailor final estimations to a user’s personal experience. The use of Hazus within the R Development environment allows for seamless integration with a user interface for inputs such as building type.

Section S2: The Composite Manning’s n:

The analysis of composite and compound channel cross-sections entails the calculation of a roughness coefficient, representing the degree of frictional resistance to flow found in a particular area. To this end, multiple formulas have been proposed and compared in the literature with differing assumptions relating the subarea forces, shear stresses, discharge, and velocity of a given channel or channel cross-section. To investigate the impact of changing the Manning’s n method on the agreement of our simulated floods with observed floods, we have selected and applied 7 Manning’s n methods: the Pavlovskii method, Lotter method, Horton method, Colebatch method, Krishnamurthy and Christensen method, Cox method, and Yen methods. A description and equation for each method is given below, such that:

\[ n_c = \text{Composite Manning’s Roughness Coefficient} \]

\[ P = \text{Wetted perimeter} \]

\[ h = \text{Water cross-sectional depth} \]

\[ n = \text{Manning’s Roughness Coefficient} \]

\[ i = \text{Subscripts denoting individual subareas of the entire compound channel section} \]
| Method       | Assumption(s)                                                                                                                                                                                                 | Equation                                                                 |
|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Pavlovskii   | The magnitude of subarea resistance forces is equivalent to the magnitude of the channel’s flow resistance force                                                                                           | $n_c = \sqrt{\frac{\sum P_i n_i^2}{P}}$                                |
| Lotter       | Total subarea discharge is equivalent to total channel discharge                                                                                                                                          | $n_c = \sqrt{\frac{PR^{5/3}}{\sum P_i R_i^{5/3} n_i}}$                  |
| Horton       | Average, disparate cross-sectional velocities are equivalent to total average cross-sectional velocity                                                                                            | $n_c = \left(\frac{\sum P_i n_i^{1.5}}{P}\right)^{2/3}$                |
| Colebatch    | Average, disparate cross-sectional velocities are equivalent to total average cross-sectional velocity                                                                                            | $n_c = \left(\frac{\sum A_i n_i^{1.5}}{A}\right)^{2/3}$                |
| Krishnamurthy| There is a logarithmic decrease in velocity as depth-from-surface increases                                                                                                                                  | $n_c = e^{\left(\frac{\sum P_i h_i^{1.5} n_i}{\sum P_i h_i^{1.5}}\right)}$ |
| Cox          | Total, weighted subarea shear velocities are equivalent to the total shear velocity                                                                                                                          | $n_c = \frac{\sum A_i n_i}{A}$                                         |
| Yen          | Total, weighted subarea shear velocities are equivalent to the total shear velocity.                                                                                                                      | $n_c = \frac{\sum \left(\frac{P_i n_i}{R_i^{1/6}}\right)}{P \frac{1}{R_i^{1/6}}}$ |
Supplementary Tables

Table S1: Hurricane Hazel Regulatory Flood vs. 100-year Return Period – Grand River Watershed

| Hydrometric Station | Upstream Area (km²) | Regulatory Flood Discharge (m³s⁻¹) | 100-Year Return Period Discharge (m³s⁻¹) |
|---------------------|---------------------|-----------------------------------|--------------------------------------|
| 02GA003             | 2966.4              | 1140.0                            | 1115.1                               |
| 02GA010             | 857.8               | 328.0                             | 355.2                                |
| 02GA013             | 689.3               | 592.0                             | 751.8                                |
| 02GA015             | 477.7               | 130.0                             | 153.3                                |
| 02GA016             | 665.7               | 168.0                             | 286.6                                |
| 02GA017             | 278.3               | 137.0                             | 177.2                                |
| 02GA018             | 452.4               | 232.0                             | 381.7                                |
| 02GA022             | 399.4               | 235.0                             | 300.7                                |
| 02GA033             | 54.5                | 21.2                              | 30.6                                 |
| 02GB001             | 4373.0              | 1100.0                            | 1495.4                               |
| 02GB006             | 137.5               | 50.4                              | 67.7                                 |
| Observed Flood Extent Polygon | Subcatchment Number | Intersection (% subcatchment area) | Excluded Observed Flood Extent Polygon Area (km$^2$) |
|-------------------------------|---------------------|-----------------------------------|-----------------------------------------------|
| FloodExtentPolygon_QC_CentralOttawa_20190503_113004.shp | 5156 | 0.039 | 0.00992 |
| FloodExtentPolygon_QC_CentralOttawa_20190503_113004.shp | 4582 | 0.127 | 0.03154 |
| FloodExtentPolygon_QC_CentralOttawa_20190503_113004.shp | 12863 | 4.047 | 0.06318 |
| FloodExtentPolygon_QC_LowerOttawa_20190429_230713.shp | 1755 | 13.90 | 2.25351 |
| FloodExtentPolygon_QC_LowerOttawa_20190429_230713.shp | 10505 | 24.055 | 14.852 |
| FloodExtentPolygon_QC_LowerOttawa_20190507_111329.shp | 1755 | 18.599 | 3.01422 |
| FloodExtentPolygon_QC_LowerOttawa_20190507_111329.shp | 10505 | 24.100 | 14.8803 |
| FloodExtentPolygon_QC_LowerOttawa_20190513_225800.shp | 12115 | 14.262 | 3.18542 |
| FloodExtentPolygon_QC_LowerOttawa_20190513_225800.shp | 9504 | 6.8904 | 1.6800 |
| FloodExtentPolygon_QC_LowerOttawa_20190513_225800.shp | 1755 | 19.830 | 3.2136 |
| FloodExtentPolygon_QC_LowerOttawa_20190513_225800.shp | 10505 | 23.722 | 14.6467 |
Table S3: Comparison of Manning’s n Methods- Grand River Watershed (RP 100) CSI Results

| Method           | 25<sup>th</sup> Percentile CSI | Median CSI | 75<sup>th</sup> Percentile CSI | Number of evaluated subcatchments |
|------------------|---------------------------------|------------|---------------------------------|-----------------------------------|
| Colebatch Method | 0.584                           | 0.729      | 0.825                           | 71                                |
| Cox Method       | 0.589                           | 0.733      | 0.824                           | 71                                |
| Horton Method    | 0.581                           | 0.726      | 0.826                           | 71                                |
| Krishnamurthy Method | 0.596 | 0.741      | 0.826                           | 71                                |
| Lotter Method    | 0.592                           | 0.733      | 0.824                           | 71                                |
| Pavlovskii Method | 0.577 | 0.726      | 0.825                           | 71                                |
| Yen Method       | 0.574                           | 0.725      | 0.825                           | 71                                |
| Range            | 0.022                           | 0.016      | 0.002                           | ----                              |
Table S4: Comparison of Manning’s n Methods - Ottawa River Watershed CSI Results

| Return Period | Method         | 25<sup>th</sup> Percentile CSI | Median CSI | 75<sup>th</sup> Percentile CSI | Number of evaluated subcatchments |
|---------------|----------------|--------------------------------|------------|---------------------------------|-----------------------------------|
| 16.52         | Colebatch Method | 0.546                          | 0.76       | 0.948                           | 21                                |
|               | Cox Method      | 0.546                          | 0.76       | 0.939                           | 21                                |
|               | Horton Method   | 0.546                          | 0.736      | 0.951                           | 21                                |
|               | Krishnamurthy Method | 0.546                      | 0.785      | 0.939                           | 21                                |
|               | Lotter Method   | 0.546                          | 0.785      | 0.939                           | 21                                |
|               | Pavlovskii Method | 0.546                       | 0.706      | 0.951                           | 21                                |
|               | Yen Method      | 0.546                          | 0.707      | 0.951                           | 21                                |
|               | Range           | 0                              | 0.079      | 0.012                           |                                    |
| 25.96         | Colebatch Method | 0.561                          | 0.803      | 0.95                            | 22                                |
|               | Cox Method      | 0.561                          | 0.803      | 0.947                           | 22                                |
|               | Horton Method   | 0.561                          | 0.762      | 0.95                            | 22                                |
|               | Krishnamurthy Method | 0.561                    | 0.803      | 0.931                           | 22                                |
|               | Lotter Method   | 0.561                          | 0.816      | 0.931                           | 22                                |
|               | Pavlovskii Method | 0.561                       | 0.752      | 0.95                            | 22                                |
|               | Yen Method      | 0.561                          | 0.752      | 0.95                            | 22                                |
|               | Range           | 0                              | 0.064      | 0.019                           |                                    |
| 26.5          | Colebatch Method | 0.752                          | 0.845      | 0.965                           | 17                                |
| Method           | 0.752 | 0.845 | 0.965 | 17 |
|------------------|-------|-------|-------|----|
| Horton Method    | 0.686 | 0.845 | 0.965 | 17 |
| Krishnamurthy Method | 0.754 | 0.849 | 0.965 | 17 |
| Lotter Method    | 0.754 | 0.867 | 0.965 | 17 |
| Pavlovskii Method | 0.682 | 0.845 | 0.965 | 17 |
| Yen Method       | 0.682 | 0.845 | 0.965 | 17 |
| Range            | 0.072 | 0.022 | 0     |    |

| Method           | 0.496 | 0.581 | 0.654 | 7  |
|------------------|-------|-------|-------|----|
| Colebatch Method | 0.496 | 0.581 | 0.654 | 7  |
| Horton Method    | 0.496 | 0.581 | 0.633 | 7  |
| Krishnamurthy Method | 0.51  | 0.581 | 0.654 | 7  |
| Lotter Method    | 0.506 | 0.581 | 0.654 | 7  |
| Pavlovskii Method | 0.496 | 0.581 | 0.633 | 7  |
| Yen Method       | 0.496 | 0.581 | 0.637 | 7  |
| Range            | 0.014 | 0     | 0.021 |    |
Table S5: Additional Binary Classification Results for the Krishnamurthy Method – Medians

|                | TPR  | TNR  | PPV  | NPV  | FNR  | FPR  | FDR  | FOR  | PT   | ACC  | BA   | F1   | FM   | BM   | MK   |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Grand RP 100   | 0.906| 0.99 | 0.883| 0.991| 0.094| 0.01 | 0.117| 0.009| 0.100| 0.975| 0.914| 0.851| 0.853| 0.828| 0.859|
| Ottawa RP 16.52| 0.941| 0.996| 0.979| 0.977| 0.059| 0.004| 0.021| 0.023| 0.065| 0.785| 0.941| 0.946| 0.826| 0.886| 0.891|
| Ottawa RP 25.96| 0.927| 0.998| 0.985| 0.973| 0.073| 0.002| 0.015| 0.027| 0.052| 0.803| 0.948| 0.946| 0.852| 0.895| 0.891|
| Ottawa RP 26.5 | 0.978| 0.992| 0.97 | 0.994| 0.022| 0.008| 0.03 | 0.006| 0.083| 0.849| 0.958| 0.964| 0.888| 0.921| 0.927|
| Ottawa RP 42.69| 0.892| 0.976| 0.668| 0.994| 0.108| 0.024| 0.332| 0.006| 0.145| 0.581| 0.97 | 0.939| 0.743| 0.755| 0.879|

TPR = True Negative Rate; TNR = True Positive Rate; PPV = Positive Predictive Value; NPV = Negative Predictive Value; FNR = False Negative Rate; FPR = False Positive Rate; FDR = False Discovery Rate; FOR = False Omission Rate; PT = Prevalence Threshold; ACC = Accuracy; BA = Balanced Accuracy; FM = Fowlkes–Mallows Index; MK = Markedness

For additional information and equations for these metrics, please see the following:

Brooks, H. et al. (2015). "WWRP/WGNE Joint Working Group on Forecast Verification Research". *Collaboration for Australian Weather and Climate Research*. World Meteorological Organisation.

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Fawcett, T. (2006). An Introduction to ROC Analysis. *Pattern Recognition Letters*. 27 (8): 861–874. doi:10.1016/j.patrec.2005.10.010.

Powers, D. M. W. (2011). Evaluation: From Precision, Recall and F-Measure to ROC, Informedness, Markedness & Correlation. *Journal of Machine Learning Technologies*. 2 (1): 37–63.

Tharwat, A. (2018). Classification assessment methods. *Applied Computing and Informatics*. doi:10.1016/j.aci.2018.08.003.

Ting, K. M. (2011). Sammut, Claude; Webb, Geoffrey I. (eds.). *Encyclopedia of machine learning*. Springer. doi:10.1007/978-0-387-30164-8. ISBN 978-0-387-30164-8.
Supplementary Figures

Figure S1: GIS Inputs for the Grand River Watershed and Ottawa River Watershed: study area (a-b), land use/land cover (c-d), and flow lines (e-f). The maps are created in Qgis with the basemaps provided by © Google Satellite Maps and © Google Street Maps under OpenLayerPlugin.
Figure S2: DGGS conversion flowcharts for raster input data (a), polygon vector input data (b), and network (directional) input data (c). The maps are created in ArcGIS with the basemaps provided by © ESRI.
Figure S3. GIS processing outputs for the Grand River Watershed and the Ottawa River Watershed: Height Above Nearest Drainage (a-b), Drainage network (c-d), and Manning’s n values (e-f)
Figure S4: GEV Distribution Regional Growth Curves – Grand River Watershed and Ottawa River Watershed

GEV Regional Growth Curves

Station Count: n = 32
Qi Sample Count: n = 1248
AIC = 1843.56
(-2)*(loglikelihood) = 1837.56

Station Count: n = 54
Qi Sample Count: n = 1487
AIC = 886.12
(-2)*(loglikelihood) = 880.12
Figure S5: Additional Binary Classification Results – Ottawa River Watershed

a) RP 26.5 True Positive Rate  
b) RP 26.5 true Negative Rate

c) RP 16.52 True Positive Rate  
d) RP 16.52 True Negative Rate

e) RP 25.96 True Positive Rate  
f) RP 25.96 True Negative Rate

 g) RP 42.69 True Positive Rate  
h) RP 42.69 True Negative Rate