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## Background

The Nova Scotia Community College's (NSCC) Applied Geomatics Research Group (AGRG) was part of an evacuation analysis undertaken by Dalhousie University & the Marine Environmental Observation Prediction and Response Network (MEOPAR), entitled, "Evacuating the Halifax Peninsula: A Multidisciplinary Analysis and Training to Improve Evacuation from Coastal Floods". The AGRG was tasked to complete the spatial flood analysis and inundation of roads infrastructure to support the evacuation analysis. The analysis required the development of an inventory of major Halifax peninsula roads impacted under various flooding scenarios, and to provide the flood extents for five flooding scenarios (Table 1). The development of this inventory involved the manipulation of spatial roads data provided by the National Road Network, as well as lidar elevation data provided by the Halifax Regional Municipality (HRM) to produce flood depth maps for Halifax. The depth maps and road inventory analysis were produced using a suite of GIS and proprietary modeling tools and software which are critical to the analysis of infrastructure vulnerability under various flood risk scenarios.

## Methodology

Flood layers were generated using an AGRG proprietary tool that raises flood water on a flat plane (known as "still-water") to inundate low areas that are hydraulically connected to the coast as described in Webster et. al, (2006). To construct a hydraulically connected DEM, culverts and bridges were derived from the intersection of the streams network (NSTDB 2012) and the roads network (National Road Network 2014), as the intersection of these datasets indicates a culvert must connect the stream underneath the road. In addition, the resulting culvert dataset was inspected for accuracy against the lidar, as well as using Google Street view as an additional tool to ensure correct interpretation of culverts and bridges. The culverts were then used to notch the DEM to allow a path for the water to move, resulting in a hydraulically connected DEM.

## Flooding Scenarios

Five flood risk scenarios were selected for the study. Three scenarios are related to the water level seen during Hurricane Juan, which made landfall in the HRM as a Category 2 hurricane on September 29, 2003 and produced a maximum recorded water level of 2.1 m CGVD28 (Forbes et al, 2009). Had Hurricane Juan occurred on a higher high water large tide (HHWLT), the water level would have been 2.9 m CGVD28 (Figure 3). If Hurricane Juan were to happen in 100 years on HHWLT after a very conservative sea level rise of 1 m in 100 years (Richards and Daigle, 2011), the water level would be 3.9 m CGVD28 (Figure 4). If a more extreme sea level rise of 5 m occurred over the next 100 years, the water level of a Hurricane Juan event happening on HHWLT would be 7.9 m CGVD28 (Figure 5). The other two scenarios are related to potential tsunamis impacting the Halifax Peninsula, as tsunamis are not an impossibility in this region. In 1929 an earthquake beneath the Laurentian Continental Slope, south of Newfoundland and east of Cape Breton, with a surface magnitude of 7.2 generated a tsunami which caused widespread destruction and 28 fatalities along Newfoundland's Burin Peninsula (Ruffman and Hann, 2006). The tsunami generated water levels 3 to 5 m above normal, which lifted houses from their foundations, tore vessels from their moorings, and destroyed virtually all property along the shore including wharves and fish stores (Ruffman and Hann, 2006). One of the largest tsunamis ever recorded occurred on December 26, 2004 in the Indian Ocean. The tsunami had wave heights of 30 m which reached 6 km inland (Paris et al, 2007). For these reasons, the water levels selected to simulate tsunamis on the Halifax Peninsula are 15 m (simulating a moderate tsunami, Figure 6) and 30 m (simulating a large tsunami, Figure 7).

5 Flooding Scenarios	
Water Level (relative to CGVD28)	Significance
2.9 m	If Hurricane Juan occurred today (2016) at HHWLT
3.9 m	Hurricane Juan + conservative 100-year Sea Level Rise of 1 m
7.9 m	Hurricane Juan + extreme 100-year Sea Level Rise of 5 m
15.0 m	Moderate Tsunami
30.0 m	Large Tsunami

Table 1. The five flooding scenarios selected for the study.  
Figure 1. A figure from Forbes et. al (2009) showing Juan's peak water level of 2.1 m CGVD28, though had it occurred on HHWLT the water level would have been 2.9 m CGVD28.

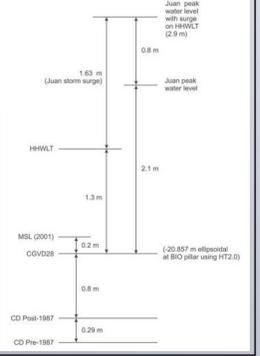


Figure 3. 2.9 m CGVD28 Flood Scenario - Hurricane Juan today at HHWLT  
Figure 4. 3.9 m CGVD28 Flood Scenario - Hurricane Juan + 1 m 100 year SLR



Figure 5. 7.9 m CGVD28 Flooding Scenario - Hurricane Juan + 5 m 100 year SLR  
Figure 6. 15 m CGVD28 Flood Scenario - Moderate Tsunami



Figure 7. 30 m CGVD28 Flood Scenario - Large Tsunami



Road Class	Flooding Scenario ↓	Length of Roads Flooded (m)	Original Length of Road (m)	% of Road Impacted by Flooding
Major Highway	2.9 m	0.0	2,732.3	0.0%
	3.9 m	0.0		0.0%
	7.9 m	0.0		0.0%
	15 m	0.0		0.0%
Major Local Road/Street	30 m	412.0	55,304.3	15.1%
	2.9 m	245.4		0.4%
	3.9 m	560.8		1.0%
	7.9 m	3,424.6		6.2%
	15 m	9,206.1		16.6%
Major Rotary	30 m	25,019.9	1,324.3	45.2%
	2.9 m	234.6		17.7%
	3.9 m	576.1		43.5%
	7.9 m	1,175.1		88.7%
	15 m	1,324.3		100.0%
30 m	1,324.3	100.0%		

Table 2. The length of each class of road affected by flooding under each flooding scenario.



Figure 8. 2.9 m CGVD28 Flood Scenario - Downtown Halifax



Figure 9. 3.9 m CGVD28 Flood Scenario - South End Halifax



Figure 10. 3.9 m CGVD28 Flood Scenario - Armdale Rotary



Figure 11. 7.9 m CGVD28 Flood Scenario - South End Halifax

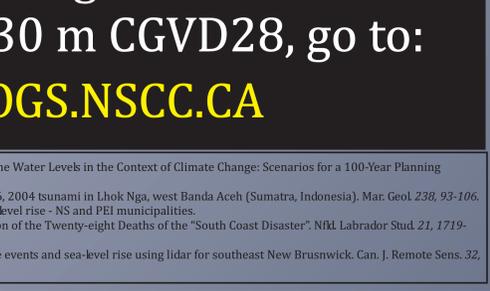


Figure 12. 7.9 m CGVD28 Flood Scenario - North End Halifax

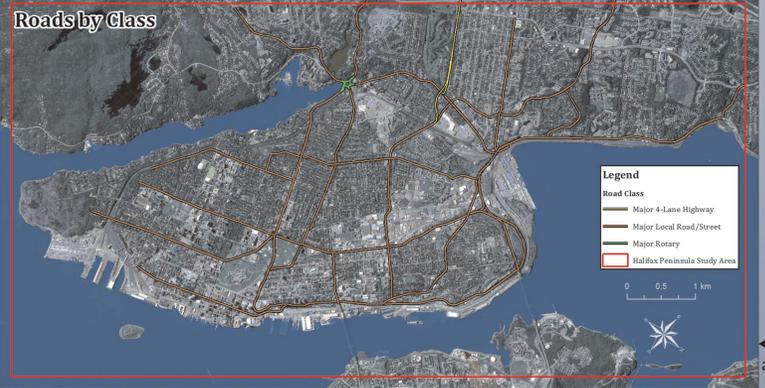


Figure 13. 15 m CGVD28 Flood Scenario - North End Halifax



Figure 14. 30 m CGVD28 Flood Scenario - South End Halifax

## Evacuation Routes used in Analysis



The length of each road by class affected by flooding under each flooding scenario was determined and is summarized in Table 2. The Armdale Rotary (road class: Major Rotary) is the most vulnerable roads infrastructure on the Halifax Peninsula.

Figure 2. The roads (by road class) assessed for flooding impacts.

For animations of flooding of the Halifax Peninsula from 0 m to 30 m CGVD28, go to:  
**WWW.AGRG.COGS.NSCC.CA**

Forbes, D.L., Manson, G.K., Charles, J., Thompson, K.R., and Taylor, R.B. (2009). Halifax Harbour Extreme Water Levels in the Context of Climate Change: Scenarios for a 100-Year Planning Horizon (Natural Resources Canada).  
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