**NASA DEVELOP National Program**



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Great Lakes Climate II

Monitoring the Impacts of Climate Change and Decreasing Water Levels on Wetlands in the Great Lakes Region of North America

 **Technical Report**

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# I. Abstract

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Wetlands, Climate Change, Remote Sensing, Land Cover Classification, Lake Water Levels

# II. Introduction

Wetlands are one of the most diverse natural systems in the world (Bardecki 1991; Cvetkovic and Chow-Fraser 2011; Midwood et al., 2012). They are transition zones between terrestrial and aquatic ecosystems and provide important ecological and economic benefits (Bardecki, 1991; Morstch, 1998). These benefits include water filtration, flood prevention, erosion control, ground water recharge, habitats for a variety of biota, and are natural carbon sinks (Bardecki, 1991; Li and Chen, 2005; Midwood et al., 2012; Mcleod et al., 2011). Despite the fact that wetlands are critical to support diverse biota, ecotourism and other economic enterprises, it has been estimated that their geographical extent has decreased up to 90% (Midwood et al., 2012). Therefore, conservation and restoration efforts for these ecosystems are crucial particularly because decreases in wetland extent will likely be exacerbated by climate change.

The Lauretian Great Lakes region of North America contains a significant amount of wetland area with more than 1500 complexes covering an area of 1700 km2 (Cvetkovic and Chow-Fraser, 2011; Herdendorf, 2004; Midwood et al., 2012). The predominant types of wetlands in the Great Lakes region are marshes and swamps (Cvetkovic and Chow-Fraser, 2011; Morstch, 1998). The Georgian Bay in Lake Huron has one of the most well preserved areas of wetlands in the Great Lakes basin and provides optimal characteristics that allow for a high diversity of biota (Cvetkovic and Chow-Fraser, 2011; Midwood et al., 2012). In contrast to that, the wetlands around Lake Ontario have faced significantly more pressures from many sources. Previous studies regarding wetlands in the northern shorelines of Lake Ontario have shown that wetland extent has decreased (Whillans, 1982). Sedimentation, natural variations, and anthropogenic influences such as urban development continue to degrade wetlands around Lake Ontario (Chow-Fraser, 1998; Chow-Fraser et al., 1998; Whillans, 1996). For instance, an urban degraded wetland in western Lake Ontario, Cootes Paradise Marsh, experienced high water levels that caused the disappearance of emergent vegetation and led to increased water turbidity (Chow-Fraser, 1998).

Water level fluctuations in the Great Lakes are dictated by climate variability (Mortsch, 1998; Mortsch et al., 2000; Wilcox and Xie, 2007). These changes in lake levels occur due to daily, seasonal, and decadal variations (Mortsch, 1998). Oscillations in lake levels have a significant influence on wetland vegetation. Short periods of high water followed by short periods of low water levels allow for maximum species diversity (Morstch, 1998; Mirwood et al., 2012; Keddy and Reznieck, 1986). Since the late 1990s, water levels in Lakes Huron and Michigan have been decreasing, affecting wetlands in Georgian Bay (Assel et al., 2004; Canada Department of Fisheries and Oceans, 2015; Sellinger et al., 2008; Midwood et al., 2012). Lake Ontario water levels have been kept more consistent for the past 50 years by a series of locks and dams that allow for more effective hydroelectric power and shipping (Chow-Fraser, et al 1998). It is not well understood how human intervention of lake levels in Lake Ontario has affected wetland extent. Moreover, climate change models predict further declines of water levels in the Great Lakes basin (Bardecki, 1991; Mortsch, 1998; Mortsch and Quinn, 1996; Sellinger et al., 2008). Climate predictions suggest a change in variables that affect water storage in the Great Lakes basin including precipitation, temperature, and evaporation (Morstch, 1998). Potential impacts of climate change might include higher precipitation amounts, warmer air temperatures, increased evapotranspiration rates, as well as declines in moisture rates leading to decreased lake levels (Mortsch and Quinn, 1996; Mortsch, 1998). A changing climate will likely modify the hydrologic cycle of the Great Lakes and, considering wetland existence depends on specific hydrologic conditions, it is imperative to understand how wetlands are currently responding to fluctuations in the water levels (Bardecki, 1991; Morstch, 1998; Wilcox, 2004). Therefore, a clear understanding of how wetlands have responded to past and current trends in lake level fluctuations will help policy-makers prepare for future changes.

This project provided updated classification maps for two geographical regions within the Great Lakes Basin: Georgian Bay in Lake Huron, Ontario and the southern portion of Lake Ontario, including Rochester, NY for the July 1987 – August 2014 period. The land cover classification maps, along with a time series animation, offer tools that highlight changes in wetlands in the Great Lakes region. The NASA national application areas addressed in this project include Climate, Ecological Forecasting and Water Resources. The goal of this project was to monitor changes in wetland extent and health due to decreasing lake levels and climate change. The Great Lakes Climate II team benefited from a partnership with the Great Lakes and St. Lawrence Cities Initiative, Georgian Bay Forever, and the Ontario Ministry of Natural Resources, which help with current wetland preservation, restoration and policy in the region. Currently, these partners do not have a cost-effective way to examine wetlands extent. This research provides a methodology that could more easily determine wetland extent in light of climate change.

# III. Methodology

In order to track fluctuations in water levels for Lake Huron and Lake Ontario between 1992 to 2013, relative changes in water levels, recorded by Topography Experiment (TOPEX)/Poseidon, Jason-1 and Ocean Surface Topography Mission (OSTM)/Jason-2 radar altimeters were downloaded. Water level data from 1960 to 2012 for Parry Sound, Ontario, Canada was acquired from *in situ* water gauge measurements compiled by Environment Canada (2014). There were no available historic *in situ* water level data for Lake Ontario and therefore were not included for the southern portion of Lake Ontario. For comparison between the two types of data at Georgian Bay, the *in situ* Parry Sound measurements were converted from the 9-year mean lake level to variance, which was the method used to report radar altimeter data. To avoid discrepancies from incongruent sampling periods, both datasets were averaged by month.

Satellite imagery used in the land cover classification for Georgian Bay and for the southern portion of Lake Ontario, were acquired from Landsat 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) for the 1987/1987 and 2013/2014 images, respectively (Table 1, Table 2). Two tiles were needed for Georgian Bay while only one was needed for the southern portion of Lake Ontario. Landsat images were selected for Georgian Bay based on historic high and historic low water levels. Lake Ontario has been heavily regulated through a series of locks and dams for over 50 years and thus does not show the same water level patterns as Georgian Bay, but a similar time scale was chosen to compare fluctuations in wetland extent between Georgian Bay and the southern portion of Lake Ontario (Chow-Fraser et al 1998). All Landsat images obtained from the United States Geological Service (USGS) Global Visualization Viewer (GLOVIS) website and were downloaded as Landsat Level 1 data.

After acquisition of the Landsat data the original digital numbers were converted to top of atmosphere reflectance through a python script in ArcGIS. The converted Landsat scenes were then mosaicked together to create one scene for the Georgian Bay tiles. Then, a 10 km buffer from the shoreline was applied using ArcGIS 10.2.2 Extract by Mask tool to define the study area. For the Georgian Bay mosaic the middle of the lake was clipped in an attempt to conserve RAM when running the R script. In other work only a 2 km buffer was necessary for classification; however, they had access to high resolution 1 m x 1 m imagery (Midwood et al., 2012). To compensate for the lower Landsat data resolution at 30 m x 30 m, a 10 km buffer was needed to include a larger area for wetland extent as a means of building upon the previously classified area.

Table 1. Landsat Imagery Information for Georgian Bay, Ontario

|  |  |  |
| --- | --- | --- |
| **Sensor** | **Scene (Path/Row)** | **Date** |
| LANDSAT 8 (OLI) | Path 19/Row 28 | June 4, 2013 |
| LANDSAT 8 (OLI) | Path 19/Row 29 | June 4, 2013 |
| LANDSAT 5 (TM) | Path 19/Row 28 | May 12, 1987 |
| LANDSAT 5 (TM) | Path 19/Row 29 | May 12, 1987 |

Table 2. Landsat Imagery Information for Rochester, Lake Ontario

|  |  |  |
| --- | --- | --- |
| **Sensor** | **Scene (Path/Row)** | **Date** |
| LANDSAT 8 (OLI) | Path 16/Row 30 | June, 2014 |
| LANDSAT 5 (TM) | Path 16/Row 30 | June, 1987 |

 Categories for the Georgian Bay land cover classification were chosen from the Southern Ontario Land Resource Information System (SOLRIS) definitions, with some modifications. Not all classification categories were needed and some were consolidated, for example at the spatial scale used in this study it was not practical to delineate specific wetland types (i.e., bog, marsh, swamp). To help avoid map clutter, the SOLRIS category “built-up area impervious” is included in the SOLRIS classification titled “urban”, which also includes transportation. Because of difficulties differentiating between forest and bedrock classes at 30 m x 30 m resolution, a class called “Forested Bedrock” was created for the portion of the northeastern Georgian Bay shoreline where bedrock exposures intermixed with forest vegetation. The two classes “Crops” and “Bare Ground” were defined in this study but classified the same under the “Undifferentiated” class in SOLRIS. Overall, ten land cover classes were created for the Georgian Bay area.

 Categories for the southern portion of Lake Ontario were chosen according to the classes identified for the National Oceanic and Atmospheric Administration’s Coastal Change Analysis Program (NOAA C-CAP) land cover classification.

Training sites were selected by examining true and false color composite images for both regions. Additional data were used for southern Lake Ontario that were not available for Georgian Bay. Training sites are representative groups of pixels that are selected and assigned to each class to delineate land cover classes. The selected pixels define the range of values associated with the spectral signatures of each individual class. Polygons, encompassing the pixels used to create a training site, were created using ArcMap for 1987 and 2013 and saved into shapefiles [Table????]. These shapfiles were then input to a Random Forests Model supervised classifier script and run using R programming software to produce the land cover classification. Additionally, Digital Elevation Model (DEM) data were obtained from ASTER, using NASA Reverb ECHO, and was used as an input to the Random Forest Model. In ArcGIS, an elevation derivative, slope, was calculated and also used as an input in the script. When the samples per training site is set to at least 1,000, the probability of random chance influencing the outputs is limited. The number of samples selected for this study was 1,500 and was selected according to Breiman (2001). Other inputs to the script included spectral bands from Landsat 5 TM (bands 1-5, 7) and Landsat 8 OLI (bands 2-7) and the thermal bands. After each classification by the Random Forests, the output map was evaluated and Training sites were added or deleted based on errors detected in an effort to improve the land cover classification.

 Upon finishing classification the land cover maps were simplified into two classes “Wetland” or “Non-Wetlands”, the latter of which includes all other classes excluding Wetlands. These simplified classifications were combined in ArcGIS to produce a four-class classification, where pixels are defined as Unchanged Non-Wetland, Unchanged Wetland, Gain of Wetland, or Loss of Wetland. Zonal statistics were used to calculate the areas of each class. This simplified classification was used to determine the changes in wetland area from 1987 to 2013 for Georgian Bay and from 1987 to 2014 for the southern portion of Lake Ontario.

 A site-specific accuracy assessment was calculated for the 2013 Georgian Bay wetland vs. non-wetland classified map. An assessment on the 1987 classified map could not be performed due to the lack of available ground truth data from that time period. For the 2013 assessment, 200 equalized random points were generated using ERDAS Imagine 2014, the generated points were added to the 2013 Landsat 8 OLI mosaicked reference image. The generated random points were evenly distributed across the classified map between wetland and non-wetland areas. The number of points met the recommended minimum requirements of at least 50 samples per class, as stated by Congalton and Green (2009). Using Google Earth imagery dated between 2004 and 2013 each random point on the reference image was classified as wetland or non-wetland by conducting a visual inspection. Google Earth was used in part because it has a higher resolution (1 m) than Landsat 5 TM or Landsat 8 OLI imagery (30 m). For the Rochester site the CCAP was used as the accuracy assessment. The CCAP is a nationally standardized database of land cover with a resolution of 30 m, database provided by NOAA.

 Using ERDAS Imagine 2014, an accuracy table comparing the classifications of each point on both the reference image and the classified map was generated [table???]. User’s Accuracy and Producer’s Accuracy statistics were derived from the data in the Error Matrix. User’s Accuracy statistics provide an indication of how likely an area classified as wetlands (or any other category) on the map would actually be wetlands if checked by a ground survey. This statistic, when subtracted from 100%, produces the error of commission, which is what percentage was over-represented in that class on the classified map. Conversely, the Producer’s statistics consider whether the ground areas were assigned into the correct class on the classified map or omitted. When the Producer’s statistic is subtracted from 100%, the result is the omission error for that class (Campbell and Wynne, 2011). Additionally, the use of the kappa statistic – estimated by kappa hat ($\hat{κ}$) – was recommended for a truer representation of classification overall accuracy (Chrisman, 1980). The kappa statistic removes the element of chance agreement from the overall accuracy percentage.



As an additional check on classification accuracy, a land cover map coinciding with the southwestern region of the study area was also used to derive an overall accuracy statistic for that section of Georgian Bay (Figure A.3). The land cover map was produced by the Ontario Ministry of Natural Resources and Forestry and obtained from the Land Information Ontario (LIO) on-line database. It was created from high-resolution IKONOS imagery, LANDSAT imagery, ground surveys and aerial imagery, which were updated as needed through 2013. The LIO map was then reclassified from sixteen classes down to two classes to produce a southwestern Georgian Bay wetlands-non-wetlands reference land cover map. The wetlands-non-wetlands map was then cropped down to the study area dimensions with the ArcMap Spatial Analyst Extract by Mask tool and overlaid with the reference map. Subsequently, 1,286 random points for the area were generated using the ArcMap Data Management Random Points tool and added to the wetlands-non-wetland classified maps. The overall accuracy statistic for the southwestern region was derived by using the ArcMap Extract MultiValues to Points tool to compare the classification values of the reference land cover map to the classified map at each randomly generated point [Table???].

NOAA C-CAP land cover data were used for an accuracy assessment of the southern portion of Lake Ontario.

# IV. Results & Discussion

Insert images, graphs, maps, charts, etc. here. Choose the most important results to highlight here. Things to discuss:

* Analysis of Results: What can you tell from your graphs, images, etc? What does this mean for your project?
* Errors & Uncertainty: What factors could you not account for, what things didn’t work out like you expected they would, etc
* Future Work: If this project was to be selected for another term, what would be the focus? What other areas would be of interest?

# V. Conclusions

Final conclusions. Word count: 200-600.

# VI. Acknowledgments

Insert here. Keep to a concise paragraph or bullets of names. End with the following sentence.

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# VIII. Appendices

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