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# Land Use and Land Cover Based Habitat Analyses of Invasive Species Along the Lower Tonawanda Creek Applying Unmanned Helicopter Remote Sensing

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Abstract:

*Trapa natans* (water chestnut) is an exotic annual aquatic plant, which is native to Eurasian and African continents. It is an invasive species in North America and has already caused serious environmental problems because of its strong capability of adaption and propagation. The objectives of this research were to survey and map water chestnut in the lower Tonawanda Creek (Erie Canal) applying unmanned aerial vehicle (UAV), evaluate the current management of controlling and removing water chestnut, and analyze how land use and land cover (LULC), as well as habitat conditions, influence the growth of water chestnut. The UAV was not only applied to detect water chestnut plants, but also used to monitor the three-dimensional habitat conditions along the lower Tonawanda Creek. The land use and land cover (LULC) classification of the study area was accomplished in ERDAS Imagine, the spatial interpolation of temperature and relative humidity was conducted in ArcGIS software environment, and the vertical changes of temperature and humidity along different cross-sections were plotted in R software environment. The results show that LULC have effect on the growth of water chestnut and environmental conditions (temperature and relative humidity). However, no strong evidence shows relationship between the growth of water chestnut and habitat conditions of temperature and humidity.

Key words: water chestnut, UAV, temperature, relative humidity, LULC

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State University of New York  
College at Buffalo  
Great Lakes Center

Land Use and Land Cover Based Habitat Analyses of  
Invasive Species along the Lower Tonawanda Creek  
Applying Unmanned Helicopter Remote Sensing

A Thesis in  
Great Lakes Ecosystem Science

by

Chenliuli Jiang

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# 1. Introduction

## 1.1 Significance of the Study

*Trapa natans*, commonly called water chestnut or water caltrop, is an exotic annual aquatic plant with a floating rosette of leaves which is native to Eurasian and African continents (Countryman, 1978; Naylor, 2003). Water chestnut is one of the most controversy plants (Hummel and Kiviat, 2004). In Asia, especially in China and India, people plant water chestnut as an agricultural species, and in Europe and Russia, it is a species of conservation concerns (Hummel and Kiviat, 2004); while the invasion of water chestnut is a serious environmental problem in North America. This plant grows easily and has already invaded freshwater rivers, pools, and lakes, including the Hudson River and the Great Lakes watershed (Akao et al., 2014; Countryman, 1978; Hummel and Kiviat, 2004).

The spread of water chestnut has already caused many ecological and economic impacts. The leaves of water chestnut cover the water surface, block the waterway, and cut off the air that fish and other aquatic lives rely on to live (NYIS, 2014; Hummel and Kiviat, 2004; Naylor, 2003). The management of controlling water chestnut has been done for several years. People applied mechanical and chemical methods to remove extensively spreading water chestnut. However, these methods of removal need a long time to ensure complete eradication and are expensive (NYIS, 2014). For example, from 1982 to 2011, state and federal agencies spent \$9,600,000 on water chestnut control in Lake Champlain (Hunt and Marangelo, 2012). Scientists also attempted to apply other biological controlling methods, for instance, introducing a leaf beetle (*Galerucella birmanica*) from Asia (Ding et al., 2006). However, whether the result of biological methods is environmental friendly is still under research and discussion.

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The study area of this research is the lower Tonawanda Creek or Erie Canal in Western New York State. The objective of this study is to apply drone or unmanned helicopter remote sensing technology and the New York State digital orthographic images to analyze micro-climate conditions and the land use types along the creek to find the distribution patterns and habitat conditions of water chestnut's growth. The current methods of controlling water chestnut spreading all have advantages and disadvantages. Improved management of the invasion of water chestnut depends on a better understanding of its habitat.

## **1.2 Objectives of the Study**

The specific objectives of this study are:

- 1) To apply unmanned aerial vehicle (UAV) as a new geographic research method for surveying and mapping the invasive plant species.

The UAV is a novel developed equipment used in recent years for geographic studies as a remote sensing and GIS data collecting platform. Unmanned helicopters with true color image sensors, as well as temperature and humidity sensors, were applied to collect data on the habitat conditions of water chestnut along research waterways. The high-resolution camera attached to the unmanned helicopter provides researchers image data that covers a large geographic area and at any time the researchers would like to deploy. This technology also provides the researchers the capability to investigate some geographic areas that we cannot easily reach. In addition to imaging sensors, the unmanned helicopter can also take some other light equipment or devices into the air for specific studies. In this research, a temperature and humidity sensor was flown in recording the data of vertical profiles above different land use surfaces. The exploration of using

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unmanned helicopters in this study can accumulate experience for doing remote sensing work in future scientific studies.

- 2) To find and locate water chestnut in the research area and evaluate the effect of current management methods of controlling and removing.

U.S. Fish and Wildlife Service (USFWS) conducted the field work of removing water chestnut invasive species since 2010 for six consecutive years (2010-2015). This U.S. federal government agency also surveyed and recorded the locations where the water chestnut was found each year. In the year of 2016, the unmanned helicopter surveying team at the State University of New York – Buffalo State College collaborated with the U.S. Fish and Wildlife Service (USFWS) to find the locations (latitudes and longitudes with images) and distributions of water chestnut plants in the lower Tonawanda Creek or Erie Canal. Comparing the records with last six years, we can evaluate the effect of the work of USFWS, and assess the locations and conditions where the water chestnut regrows.

- 3) To find the regular growing pattern of water chestnut and analyze the habitat conditions in the study area.

In this research, temperature and relative humidity in the study area were sampled both in cross-sections along the waterway and in vertical profiles from the ground to the 12 m above the ground. Analyses of the relationships between the micro-habitat conditions and land use types from the inland locations to center line at the creek waterway may provide us a general view that the conditions allowing the water chestnut to thrive.

The original hypotheses of this study are:

- 
- 1) The micro-habitat condition of temperature (°F) and relative humidity (RH) along the lower Tonawanda Creek does change drastically from the creek centerline to the inland directions, which is that temperature goes up and relative humidity goes down;
  - 2) Both the micro-habitat condition and the LULC do influence the distribution of water chestnut. Water chestnut grows more in the place having higher temperature, lower relative humidity and more human activities in the surroundings.

## **2. Literature Review**

### **2.1 Biological Properties of Water Chestnut**

*T. natans* (water chestnut) belongs to the Lythraceae family, Trapoideae subfamily. The plants die at the end of every growing season and regrow in the spring of next year. *T. natans* has two types of root: the fine root anchoring the plant into the mud, which looks like wires and was born in sediment; while, the other type is photosynthetic root, which is light green or dark brown with pinnate fine crack (Flora of China, 2007). Its stem is 2.5-6 mm in diameter. The petiole of the plant is 5-18 cm long and is swollen distally with pubescence, which is the stalk attaching the leaf blade to the stem (NYIS, 2014). Its leaf blade is glossy and dark green adaxially, greenish purple abaxially, and often with colored spots between veins (Figure 1). The leaf blade is deltoid-rhombic to oblate-rhombic with pubescence in the back. The leaf base is broadly cuneate and the leaf margin is irregularly dentate distally (Flora of China, 2007). The floating leaves bear in a rosette at the water surface, and each rosette is capable of producing 10 to 15 nuts, and each of which carries 6 g wet mass (2.1 g dry mass) and 2 to 4 cm wide at maturity (Hummel and Kiviat, 2004). Its petals are white. The fruit is turbinate to shortly rhombic, horned, with a prominent bulge at the crest, and the fruit has tetragonal to rounded or dome-shaped crown and is

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rarely crownless (Flora of China, 2007). Generally speaking, *T. natans*' flowers bloom in May to October, and it produces fruits in July to November. The fruits grow under water and the individuals go directly beneath their parent plants to prepare for propagating. The parent plant is killed by frost in autumn and decomposes quickly (Hummel and Kiviat, 2004). The seeds can remain dormant in the bottom of sediment for 10-12 years (NYIS, 2014; Muenscher, 1944; Winne, 1950). The seeds can also be spread by shipping, boating, or animal activities, such as ducks and waterfowl. Water chestnut grows best in waterbodies with a pH range of 6.7 to 8.2 (Naylor, 2003).



Figure 1 Water Chestnut (Download from: PlantPhoto.cn)

The mature fruits of water chestnut contain various nutrients including protein and starch. Therefore, water chestnut has been regarded as food and medicinal material since ancient times in China, India and countries in Southeast Asia (Zhu, 2016; Hoque et al., 2009).

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## 2.2 Invasive History of Water Chestnut in North America

Overgrowth of water chestnut has been a regional environmental issue throughout North America (Akao et al., 2014), especially in the northeast of United States. Water chestnut was introduced as an ornamental in Massachusetts in the mid-1870s first, and was cultivated in the botanical garden at Harvard University in late-1870s (Countryman, 1978). Since that time, water chestnut started to spread in Massachusetts. In the 1880s, a plant lover brought water chestnut into New York State after touring Europe (Hummel and Kiviat, 2004). Then, water chestnut spread into several lakes and creeks. The flood caused by locks and dams of the New York Barge Canal system allowed water chestnut to escape from the original spreading areas (Winne, 1950). This species grew well and had covered roughly 405~486 hectares of the Mohawk River in 1934 via Collins Creek where water chestnut firstly introduced into (Winne, 1950; Countryman, 1978). It also reached the Hudson River from the Mohawk by the late-1930s (Muenscher, 1937; Hummel and Kiviat, 2004). According to literature, the total area of infestation in New York State by 1952 was estimated at 1416 hectares (Countryman, 1978). In addition to the Hudson River, water chestnut was found infestations in a marshy waterfowl impoundment, numerous artificial and partly natural ponds, and one major tributary within 30 km of the Hudson River, especially Dutchess County, New York (Besha and Countryman, 1980; Kiviat, 1993; Tiner, 2000).

Water chestnut probably reached Lake Champlain from the Hudson River via the Hudson-Champlain Canal by the seeds clinging to boats, which was first found from the southern end of Lake Champlain in 1940s (Countryman, 1978). The species spread to four other water bodies in Vermont (Bove and Hunt, 1997); it continued to travel north and was observed in southern Quebec, Canada in around 1997 (Hummel and Kiviat, 2004). By 1919, water chestnut was

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discovered in a Potomac Park fish pond in Virginia (Gwathmey, 1945). Prior to 1964, the species was found in four waterways in Maryland, which are all tributaries of Chesapeake Bay (Bickley and Cory, 1955; Countryman, 1978).

### **2.3 The Impacts of Water Chestnut Invasion**

Invasive species can have serious impacts on the native ecosystems, ecologically and economically (Mills et al., 1993). From the viewpoint of ecology, the mats of water chestnut can block sunlight penetration into the water and reduce the growth of native aquatic plants beneath the water chestnut canopy (NYIS, 2014). The mats also can block the oxygen dissolving into the water which may result in the death of fishes, preventing most water uses, and creating habitats of mosquitoes (Naylor, 2003). From the viewpoint of economy, the federal and state agencies spent a lot money to remove water chestnut (NYIS, 2014). The death of fish causes loss in fishery, and the block of waterways causes loss in tourism and shipping industry (Naylor, 2003; Hummel and Kiviat, 2004).

### **2.4 The Management and Control of Water Chestnut**

In 1949, New York State enacted a law prohibiting planting, transporting or trafficking in plants, seeds or nuts of the water chestnut (Hummel and Kiviat, 2004). Since then, the states in which water chestnut was introduced enacted similar laws, and listed water chestnut as posing an ecological or economic threat (Hummel and Kiviat, 2004). In addition to prohibiting planting water chestnut in the law, removal effects and education were also applied simultaneously.

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### **2.4.1 Chemical Control**

A herbicide, 2,4-dichlorophenoxy acetic acid (2,4-D), was applied to the Mohawk River, the Hudson River, and Lake Champlain. This action reduced water chestnut population successfully (Greeley, 1960; Countryman, 1978; Rector, et al., 2015). But under the effect of 2,4-D in high concentrations, many native wetland plants, fish, and aquatic invertebrates were also impacted (Cronk and Fennessy, 2001; Countryman, 1978; Kiviat, 1993).

### **2.4.2 Physical Control**

Physical control is the most common method used to remove water chestnut, which is often combined with chemical control. Water chestnut, as an annual plant, is better to be removed the rosettes before fruits mature and seeds fall down to the bed of the waterways (Hummel and Kiviat, 2004), which is exactly what USFWS is doing in the Tonawanda Creek and Erie Canal waterways. Generally speaking, physical control can be accomplished with machines, such as underwater cutters and harvesters, or by hand pulling (Countryman, 1978; NYIS, 2014). During the mechanical removal process, workers should be careful not to release any mature fruits to fall into sediments; the process should also be ensured to outlive any potentially activated seeds hiding in sediments, which could be dormant for 10-12 years (Elser, 1964). Therefore, the annual control activities should be done no later than July before mature fruits may start to drop (Countryman, 1978).

Physical control methods have been proved effectively in many cases, such as the management plans in Lake Champlain, the Hudson River, Chesapeake Bay, the Potomac River, as well as other water bodies (Bickley and Cory, 1955; Elser, 1964; Hunt and Marangelo, 2012; Bove and Hunt, 1997; Madsen, 1993). However, physical control methods always last a long time and cost



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a lot of money and human resources. In the case of controlling water chestnut in the Potomac River, for example, it cost several hundred thousand dollars and took more than 20 years to achieve the successful result (Madsen, 1993).

### **2.4.3 Biological Control**

The basic idea of biological control of invasive species is to use the natural enemy of the species. In order to control water chestnut, several different species were introduced to establish the competition. According to literature records, grass carp (*Ctenopharyngodon idella*) has been introduced from Europe and has controlled water chestnut in some regions (Krupauer, 1971); a pathogenic fungus, *Sclerotium hydrophilum* Sacc., which was cultured from a diseased plant, is found can be used to kill young rosettes of water chestnut (Hall, 1982); a herbivorous insect species, *Galerucella birmanica* Jacoby (Coleoptera: Chrysomelidae), regarded as the most promising species, was introduced from China (Ding et al., 2005). However, these species all have their specific problems in controlling water chestnut. The grass carp should be monitored because this kind of fish may also destroy other native species, and may escape from where people expect it to stay; the fungus should be artificially cultured in every spring; the leaf beetle can only damage part of the leaf tissue rather than the entire plant. Therefore, it cannot guarantee in stopping the regrowth of water chestnut (Krupauer, 1971; Hall, 1982; Ding et al., 2005).

## **2.5 The Effects of Habitat Conditions**

The variety of habitat conditions is one of the most important factors affecting species diversity. The habitat conditions include landforms, such as elevation, aspect, and slope angle (Forman, 1990; Moore et al., 1993); soil-water distribution (Del Barrio et al., 1997); climate factors, such as solar radiation, precipitation, temperature, etc.

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The climate condition is considered as the main factor influencing regional vegetation types and their distribution (Woodward and McKee, 1991), especially in small geographic research regions with large map scale and detailed investigations. In many studies, scientists indicated that climate change and invasive species are two serious factors causing habitat alterations posing challenges for the management of native species including those of conservation concerns (Rahel et al., 2008; Rahel and Olden, 2008; Havel et al., 2015). The largest challenge for species caused by climate change is an alteration of thermal regimes. Most aquatic organisms, especially aquatic animals, are sensitive to temperature since they are ectothermic (Rahel and Olden, 2008). Many non-native species stocking in human-made facilities, such as water gardens and aquacultures, become more widespread and extend northward because of the warmer environment and the milder winters (Rahel and Olden, 2008; Maki and Galatowitsch, 2004).

Water chestnut as an aquatic invasive species is also sensitive to climate, for example, Rector et al. (2015) indicated that in a laboratory experiment, water chestnut fruit frozen in water for 35 days would not germinate, while simulated drawdowns did not obviously affect its seed germination. The lower Tonawanda Creek crosses both urban area and rural area, which may produce differences in thermal regimes. These differences can impact the water chestnut growth.

## **2.6 Land Use and Land Cover Classification**

Land use and land cover (LULC) are two important geographic categories which record socio-economic activities and land management practices (Comber, 2008). Many researchers treat them as interchangeable concepts (Veldlamp and Verburg, 2004). LULC classification is one of the most widely used applications in remote sensing (Saadat et al., 2011). Although some

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professional institutes and government departments published LULC classification criteria, many studies still created their own classification categories.

For instance, Colditz et al. (2011) did a study in both South Africa and Germany. They recoded the legend to six basic classes in South Africa, which were “woodland”, “shrubland”, “water”, “wetland”, “agriculture”, and “urban”. However, in Germany, classes “mixed forest” and “heterogeneous agriculture” were overestimated which is particularly obvious for the latter in northwestern and southeastern Germany. Therefore, the LULC was classified into five categories, which were “urban”, “agriculture”, “forested and semi-natural land”, “wetland”, and “water” (Colditz et al., 2011).

In some research, land use and land cover would be classified separately. For example, Saadat et al. (2011) did LULC classification that covers a large area in Iran. In their study, LU was classified into six categories as follows: irrigated farming (IF), dryland farming (DF), forest (F), rangeland (R), urban (U), and water bodies (W); then, according to vegetation density, forest and rangeland were further classified into LC: high density forest (F1, cover >70%), medium density forest (F2,  $40\% < \text{cover} \leq 70\%$ ), and low density forest (F3, cover  $\leq 40\%$ ); high density rangeland (R1, cover >30%), medium density rangeland (R2,  $15\% < \text{cover} \leq 30\%$ ), and low-density rangeland (R3, cover  $\leq 15\%$ ). Jansen and Gregorio (2002) indicated that traditional LULC classification systems were limited in their capacity of storage of a large number of classes and often could not contain the entire variety.

## **2.7 Spatial Analyses of Invasive Species Applying Remote Sensing and GIS**

Geographic Information System (GIS) and remote sensing (RS) are two powerful technologies used worldwide to analyze invasive species (Joshi et al, 2004; Masocha and Skidmore, 2011).

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### **2.7.1 Applications of Remote Sensing**

Walsh et al. (2008) processed QuickBird and Hyperion satellite data to characterize the areal extent and spatial structure of guava in the Galapagos Islands of Ecuador. Asner et al. (2008) conducted a research using remote sensing technology to detect and map invasive species in the Hawaiian forests. They used Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), and found that native species and invasive species had generically different reflectance and derivative-reflectance signatures. In another research, light detection and ranging (LiDAR) system was combined with AVIRIS to detect invasive species (Asner et al., 2008). Asner et al. (2008) deployed a new hybrid airborne system combining the Carnegie Airborne Observatory (CAO) small footprint LiDAR system with the AVIRIS to map the three-dimensional spectral and structural properties of Hawaiian forests, where the LiDAR sub-system built the model to detect canopy height and top-of-canopy surfaces.

### **2.7.2 Applications of GIS**

In addition to mapping invasive species, interpolation and building spatial statistical model are two widely used methods to conduct spatial analyses in geographic information systems (GIS). Ninyerola et al. (2000) developed a multiple regression method to analyze the meteorological variables and geographical variables. They proposed an empirical methodology for modeling precipitation. In their research, interpolation techniques were applied to analyze each of the elements (Ninyerola et al., 2000) and Geographically Weighted Regression (GWR), which is a spatial statistical model, was used in GIS environment (Fotheringham et al., 2002; Brunsdon et al., 2007). GWR model can conduct statistical analyses among spatial variables and estimate correlation coefficients at different geographic locations. The GWR then can display the analytical results on 2-dimensional maps (Fotheringham et al., 2002).

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Interpolation is commonly used in climate analyses. Jeffrey et al. (2002) used spatial interpolation to construct a comprehensive archive of Australian climate data. They built their own model and analyzed temperature, vapor pressure, evaporation and other climate factors (Jeffrey et al., 2002). Goovaerts (2000) used kriging interpolation to analyze rainfall.

### **2.7.3 Applications of Unmanned Aerial Vehicle (UAV)**

In recent years, unmanned aerial vehicle (UAV) becomes more and more popular in the researches and applications of remote sensing. UAV is not only used in scientific work but also used in many other fields. Advances in design, sensors, electronics, and batteries have enhanced the development of UAV. Some researchers and engineers have built micro-UAVs which are 0.1-0.5 m in length and 0.1-0.5 kg in mass (Michael et al., 2010). The broad availability of UAV worldwide, the miniaturization of sensors on board, and the reduction of the cost of UAVs are all advantages making the equipment more powerful in comparison to traditional remote sensing techniques (Laliberte et al., 2010; Honkavaara et al., 2013). For applications, Honkavaara et al. (2013) introduced the usage of UAVs in agriculture and forestry. In forestry studies and management, UAVs are used for forest fire detection, monitoring for legal restrictions and evidence in violations, locating harvest sites and inspecting forestry operations, etc. In agriculture, UAVs are used for field trials and researches, surveys of the biomass and crop growth, etc. (Honkavaara et al., 2013)

## **3. Methodology**

### **3.1 The Study Area**

Tonawanda Creek is located in the western part of New York State, US (Source: 42.658056 N, 78.319167 W; Mouth: 43.023611 N, 78.881667 W), which is a tributary of the Niagara River.

The entire creek flows through the counties in order of Wyoming, Genesee, Erie, and Niagara. The channel of lower Tonawanda Creek was used as the lower reach of the Erie Canal during the historical period. Stream in this reach flows southbound from the Town of Tonawanda to the City of Buffalo, and turns to the east direction before joining into the Niagara River. The lower Tonawanda Creek, which is also the lower Erie Canal, is selected as the study area of this research. In particular, the section of the creek we studied is from the confluence of the Tonawanda Creek and Erie Canal to the mouth of the Tonawanda Creek entering into the Niagara River.

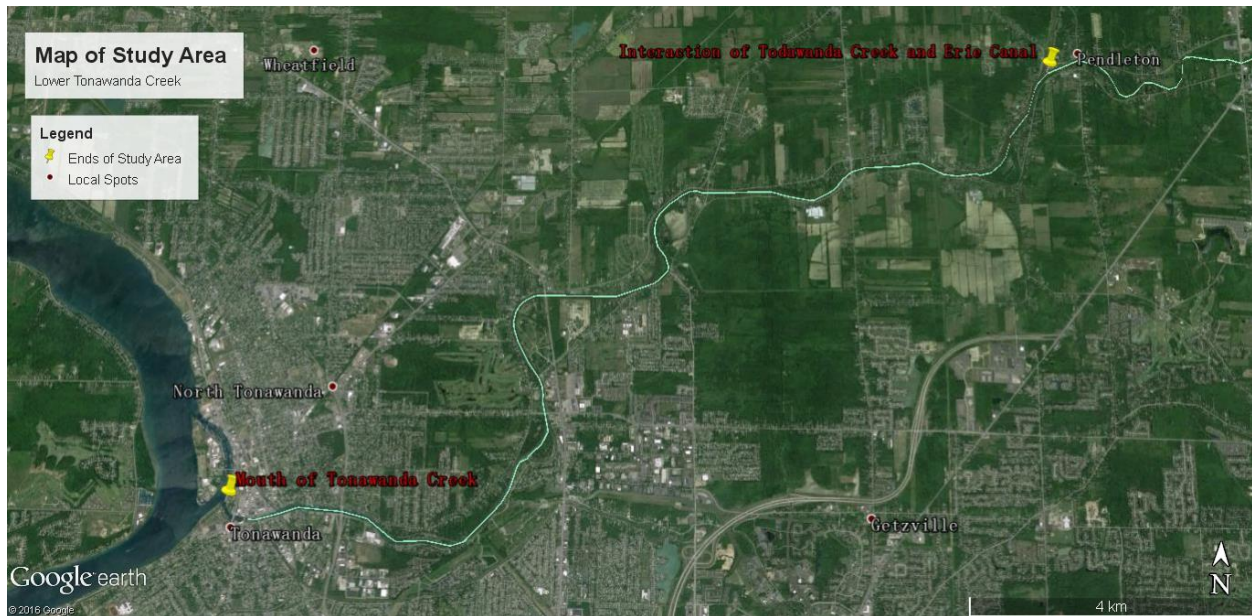


Figure 2 The Map of Study Area

The lower Tonawanda Creek is between the two yellow pushpins (Printed in Google Earth Pro 7.1.4.1529).

All segments of Tonawanda Creek are impaired or stressed of their designated uses, such as fish consumption or recreation that are impaired or stressed (NYSDEC, 2010). The lower Tonawanda Creek was impacted due to several reasons, including toxic contaminants and residential sewage

discharges from failing and/or inadequate on-site septic systems in the watershed. This reach of the creek is also a navigable waterway with many private docking sites of ships and boats.

### 3.2 Data Collections

The data was collected mainly during two time periods in this study. In the first period, we selected seven virtual transects along the study reach and applied the UAV that carries a HOBO weather data logger to record temperature and relative humidity (RH) in vertical profiles along each of transects. Five to seven vertical profiles were surveyed along each of transects across the creek. Two or three profiles were surveyed on each side of the river, and one profile at the center of the water in the river on a cross-section. The micro-temperature and relative humidity survey was accomplished in early August of 2016. The survey of water chestnut distributions on the water ways was conducted in the middle of July, 2016.

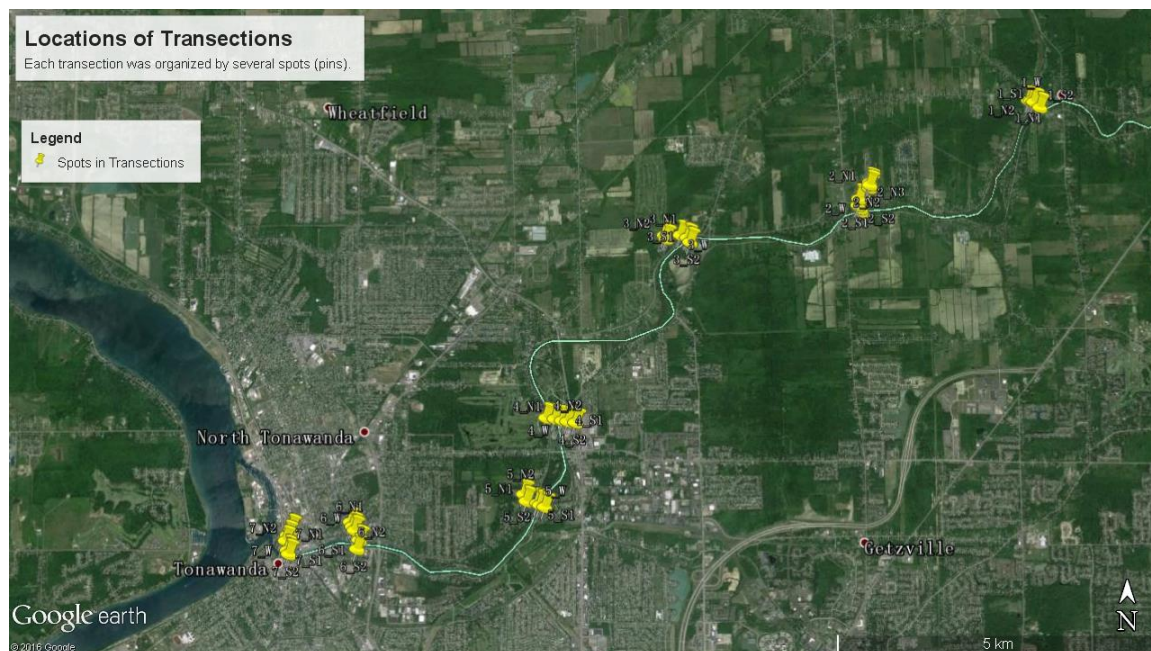


Figure 3 The Locations of the Field Transects

Each transect was organized by five or seven vertical profiles (pushpins) (Printed in Google Earth Pro 7.1.4.1529). The transects were numbered 1 to 7 from east to west.

---

### 3.2.1 Applying UAV Remote Sensing

DJI Phantom 2 Vision+ and DJI Phantom 3 Standard were applied as the remote sensing platform. Phantom 2 Vision+ is a light weight unmanned helicopter with a 3-axis gimbal to stabilize the true color camera under its body, which can take digital images in whatever direction (Da-Jiang Innovations Science and Technology Co., Ltd. Shenzhen, Guangzhou, China) from horizontal ( $0^\circ$ ) to vertical ( $90^\circ$ ). The drone utilizes DJI VISION mobile application on a popularly used device, such as a smartphone or a tablet PC to control the aerial camera sensor and monitor the view of the flying camera or sensor. The flying camera or sensor records images with GPS position information at a resolution of  $4384 \times 2466$  pixels.

DJI Phantom 3 Standard is the upgraded UAV with a high-precision camera and more stable flight control system, which was manufactured by the same company as the Phantom 2 vision+. In this study, the resolution of images was set the same as the Phantom 2 vision+. It has better safety performance and uses a new mobile application (APP) DJI GO to control its flying status. The remote control software can set maximum elevation and distance in this new APP to keep the drone within a safe flying area. The helicopter or drone will automatically stop and stay inside of the selected range limits. In the APP, the pilot can watch the live GPS map to see where the aircraft is and know which direction it is facing and guide it back to the pilot location or home location in an instant. The light weight of the aircraft is an advantage that makes the DJI drones portable. The DJI phantom system has limited battery durations. Even though the batteries of the Phantom 3 standard was improved and can last a longer time than the batteries of Phantom 2 vision+, one still can only fly for about 20 minutes per battery.





Figure 4 The DJI Phantom 3 Standard UAV

### 3.2.2 Collection of Temperature and Relative Humidity Data

The portable meter recording the atmospheric data is HOBO Temperature/Relative Humidity Data Logger, model U10-003 (Onset Computer Corporation, Bourne, Massachusetts, the United State). The temperature range of the data logger is  $-4^{\circ}\text{F}$  to  $158^{\circ}\text{F}$  ( $-20^{\circ}\text{C}$  to  $70^{\circ}\text{C}$ ), and the relative humidity range is 5% to 95%. During the first data collecting period, the UAVs were applied from the ground to the height of around 12 meters in each of the vertical profiles. The layer from the ground to 12 meters height has been divided into 12 levels, which means 1 meter per record. The UAVs stopped for two minutes on each level to make sure that the data logger recorded the exact temperature and relative humidity of that height. The data logger was set to take one sample per second. The data was exported in HOBOWare of Onset Applications on a lab computer and were analyzed in the statistic application, R 3.2.0.



Figure 5 U12-011 HOBO Data Logger

The time period of flying UAVs at a particular spot was gauged by the alarm on the smartphone. The HOBO data logger recorded the temperature and relative humidity data with time stamps. When doing the field investigations, the height displayed at the bottom of the device screen controlling the unmanned helicopters was contracted at the time. Then in the lab work, the temperature and relative humidity data could be matched with the elevation data.

### **3.3 Land Use and Land Cover Analyses**

The original data were digital ortho-imageries, which were downloaded from NYS GIS Clearinghouse (<http://gis.ny.gov/gateway/mg/index.html>; <http://www.orthos.dhSES.ny.gov/>).

#### **3.3.1 Unsupervised Land Use-Land Cover Classification**

The unsupervised classification was conducted in the environment of a remote sensing software, ERDAS Imagine (Hexagon Geospatial, Inc., Norcross, Georgia, US). Unsupervised and supervised classifications are two basic approaches of digital image classification with the goal of producing classification maps of geographic features using remotely sensed images including land use or land cover maps (Rundquist, 2010). The two most commonly used unsupervised classification algorithms in ERDAS Imagine are K-means and the Iterative Self-Organizing Data Analysis Technique (ISODATA) (Rundquist, 2010).

---

The entire area was mosaicked by 57 patches of downloaded digital ortho-imageries. First, the 57 images were input into ERDAS 2016 (Figure 6). Then, the MosaicPro tool was applied to (Figure 7) mosaic the patches into one image. After the images of the study region were combined, unsupervised classification was conducted. According to the actual conditions of the study area, we selected five different classes or categories for the unsupervised classification, which were waterbody, urban, lawn, bare soil, and forest. Verifying the different LULC, the various LULC classes were entered in the attribute table that was generated by unsupervised classification.

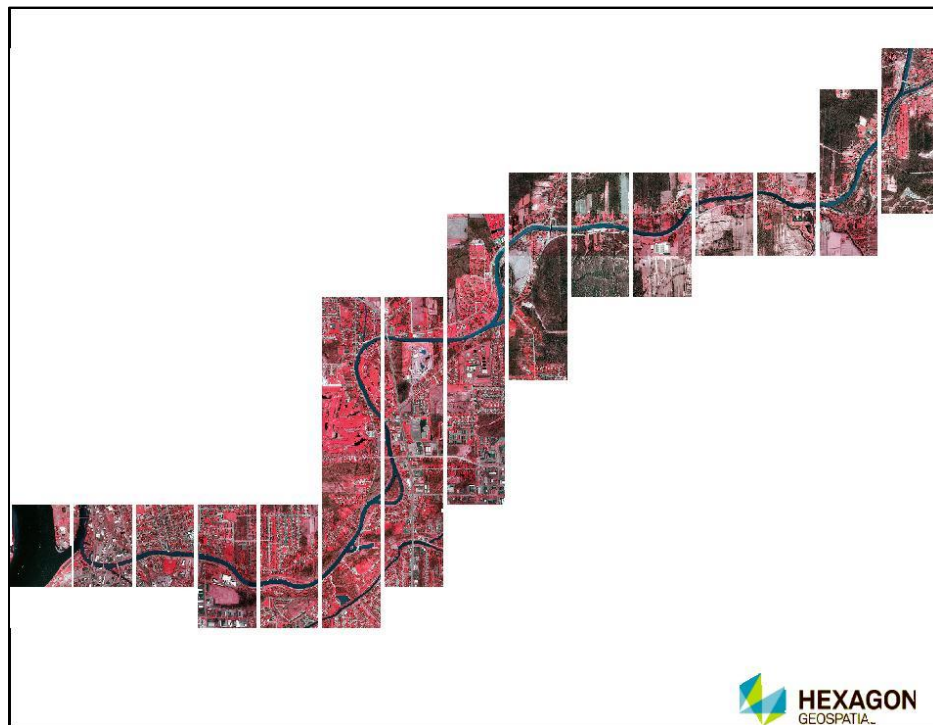


Figure 6 The Entire Study Area in ERDAS Imagine (57 patches)

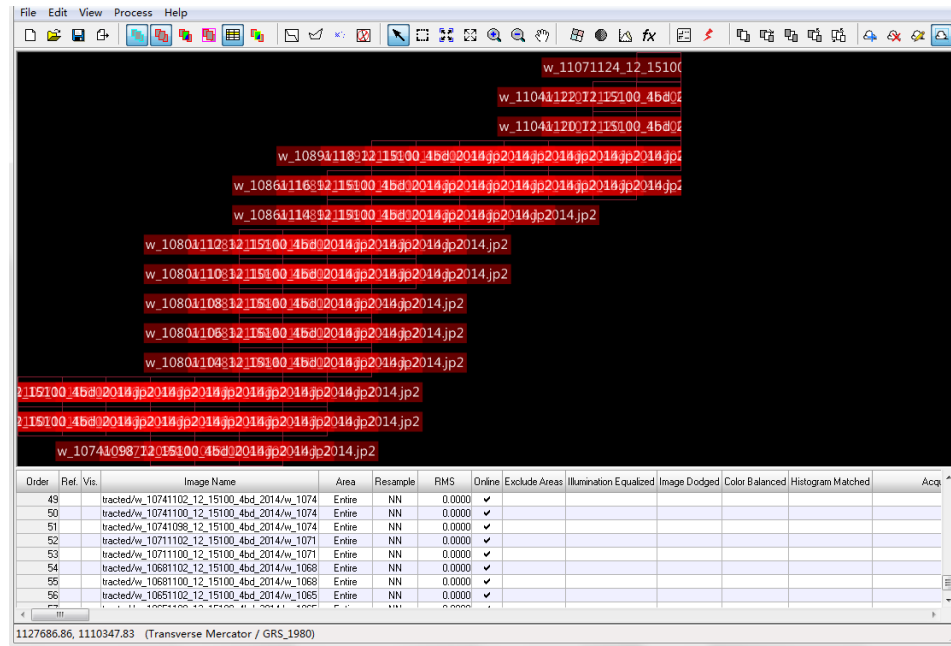


Figure 7 The MosaicPro Tool in ERDAS 2016

### 3.3.2 Normalized Difference Vegetation Index (NDVI)

In many studies, some indices are used to evaluate the land cover (Chen et al., 2004; Manandhar et al., 2009). In this study, the normalized difference vegetation index (NDVI) is selected to further explain LULC classification in the study area. The NDVI is defined as:

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)} \quad (1)$$

where NIR and VIS represent surface reflectance averaged over ranges of wavelengths in the visible ( $\lambda \sim 0.6 \mu\text{m}$ , “red”) and near infrared, IR ( $\lambda \sim 0.8 \mu\text{m}$ ) regions of the spectrum (Carlson and Ripley, 1997). As designed, the NDVI varies between -1.0 and +1.0. It is functional, but not linear, equivalent to the simple infrared/red ratio (NIR-VIS) (Carlson and Ripley, 1997). The calculation was done in a different software application of remote sensing, the Environment for Visualizing Images (ENVI) Version 5.0 (Exelis Visual Information Solutions, Inc., Boulder, Colorado, US). ENVI is widely used in remote sensing and image analyses. It combines

---

advanced image processing and geospatial technology to extract information that the researchers needed from imagery. NDVI, as a well-developed concept, was built as a permanent tool in the toolbox of ENVI. Therefore, it can be calculated easily and directly, and then used to create greyscale images.

### **3.4 Statistical Analyses**

The temperature and relative humidity data recorded by the HOBO data logger were sorted in Microsoft Excel, according to the field work time for the 37 vertical profiles, the temperature, relative humidity, and altitude data were reorganized to build the statistical model. To reduce the errors caused by the different data collecting time in a day, the differences between temperature or relative humidity at higher altitudes and ground or surface data were used to conduct the analyses. The statistical data were saved as comma separated values files (\*.csv). The files were imported into the statistical software, R 3.2.0 (R Development Core Team, New Zealand) and regression analyses were conducted.

### **3.5 Spatial Analyses**

#### **3.5.1 Spline Interpolation**

Spatial Interpolation is the process of identifying the  $z$ -value at a new location based on the characteristics of  $n$  adjacent control points (Jensen and Jensen, 2013). In this study, the  $z$ -value is temperature or relative humidity. In the process of spatial interpolation, there should be an assumption that the sampling points of observations have accurate  $x$ - and  $y$ -coordinates, accurate  $z$ -values, and are associated with an appropriate map projection and datum (Jensen and Jensen, 2013). There are several commonly used interpolation methods, such as Inverse-Distance-Weighting (IDW) interpolation, Kriging, Natural Neighbor, Spline, Trend, etc.

---

The relationship and difference between Kriging and splines have been discussed. Kriging is the best choice for phenomena with a strong random component or for estimation of statistical characteristics; while splines rely on a physical model flexibility provided by change of elastic properties of the interpolation function (Mitas and Mitasova, 1999). Since the field data sampling sites were designed regularly and were not random, we need to use an interpolation method that can fit the data and is not statistical. Therefore, we applied spline interpolation, to analyze temperature and relative humidity. Spline interpolation is a method using a mathematical function that minimizes overall surface curvature to estimate values (Childs, 2004). When using this method, the smooth surface formed by the interpolation results passes exactly through those input points (Childs, 2004). This method is commonly used to predict ridges and valleys and is the best approach to representing the smoothly varying surface of phenomena such as climatological variables (Childs, 2004; Hutchinson, 1995; Ninyerola et al., 2000). The algorithm of the spline model uses the following formula to do the surface interpolation:

$$S(x, y) = T(x, y) + \sum_{j=1}^N \lambda_j R(r_j) \quad (2)$$

where:

$j=1, 2, \dots, N$ ;

$N$  is the number of points;

$\lambda_j$  are coefficients found by the solution of a system of linear equations;

$r_j$  is the distance from the point  $(x,y)$  to the  $j^{th}$  point;

$T(x,y)$  and  $R(r)$  are defined differently, depending on the selected option (ArcGIS 10.4.1).

---

There are two spline types: regularized and tension. The regularized type creates a smooth and gradually changing surface with values that may lie outside the sample data range; the tension type controls the stiffness of the surface according to the character of the modeled phenomena (Childs, 2004). In this research, we chose the tension type. For the tension type,

$$T(x, y) = a_1 \quad (3)$$

where:

$a_1$  is a coefficient found by the solution of a system of linear equations;

and,

$$R(r) = -\frac{1}{2\pi\varphi^2} \left[ \ln\left(\frac{r\varphi}{2}\right) + c + K_o(r\varphi) \right] \quad (4)$$

where:

$r$  is the distance between the point and the sample;

$\varphi^2$  is the weight parameter;

$K_o$  is the modified Bessel function;

$c$  is a constant equal to 0.577215 (ArcGIS 10.4.1).

The interpolation work was done in ArcGIS 10.4.1 environment (ESRI, Inc., Redlands, California, US). The spline tool could be found in Arc ToolBox under 3D analyst toolbox, and the  $z$ -value in this research is either temperature or relative humidity in each of the profiles.

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### **3.5.2 Mapping Water Chestnut Records**

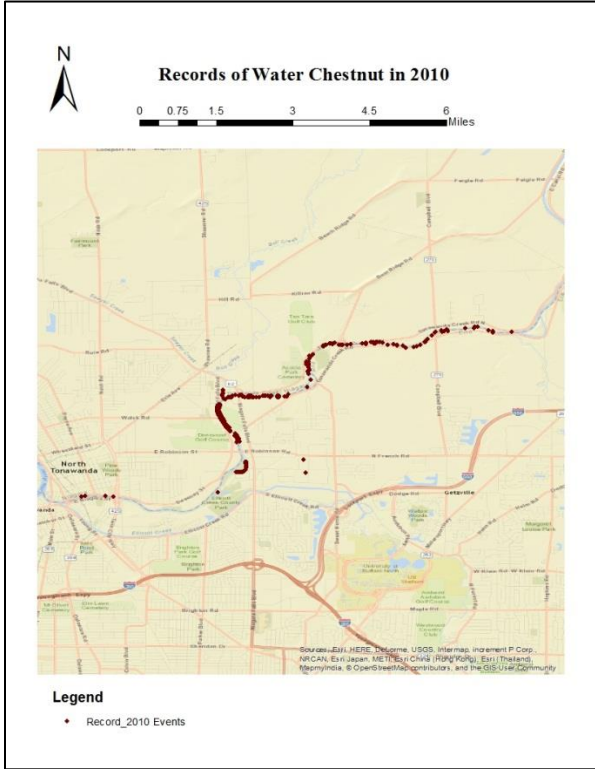
The Lower Great Lakes Fish and Wildlife Conservation Office conducted the removal of water chestnut every summer in the lower Tonawanda Creek from 2010 to 2015. The researchers and government employees recorded the locations of water chestnut each year and then sorted and plotted all the six-year records into ArcGIS shapefiles. In this study, the water chestnut records of each year were mapped in ArcGIS 10.4.1 respectively.

## **4. Results**

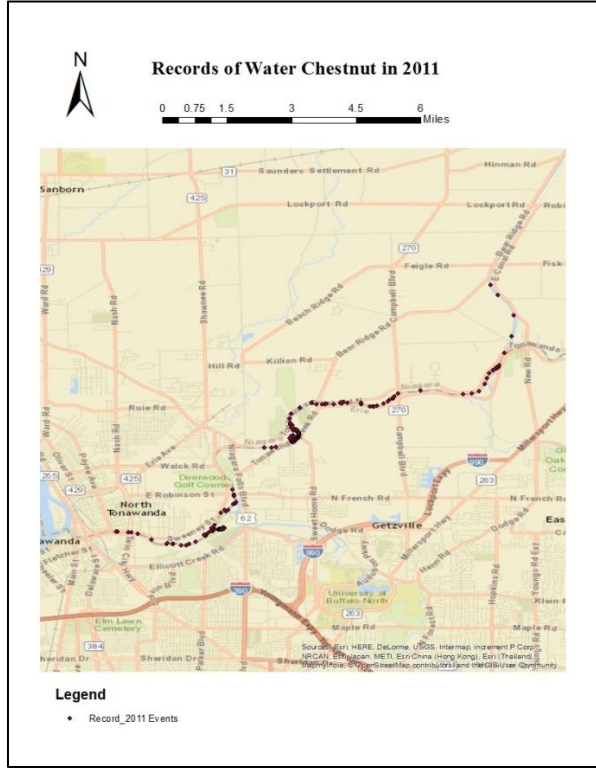
### **4.1 Locations of Recoded Water Chestnut Invasions in 2010-2016**

Along the lower Tonawanda Creek, the physical removal of water chestnut has been conducted during 2010 to 2016 by the Lower Great Lakes Fish and Wildlife Conservation Office. The researchers and biologists recorded the locations of the plants and whether the plants were pulled physically. According to the ArcGIS shapefile that the government agency provided, the locations, where water chestnut was found, are shown on the following maps (Figures 8).

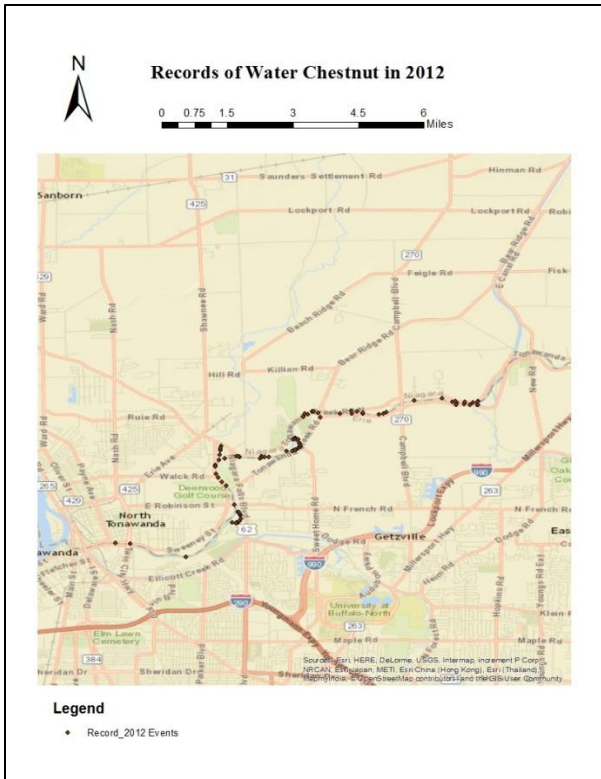




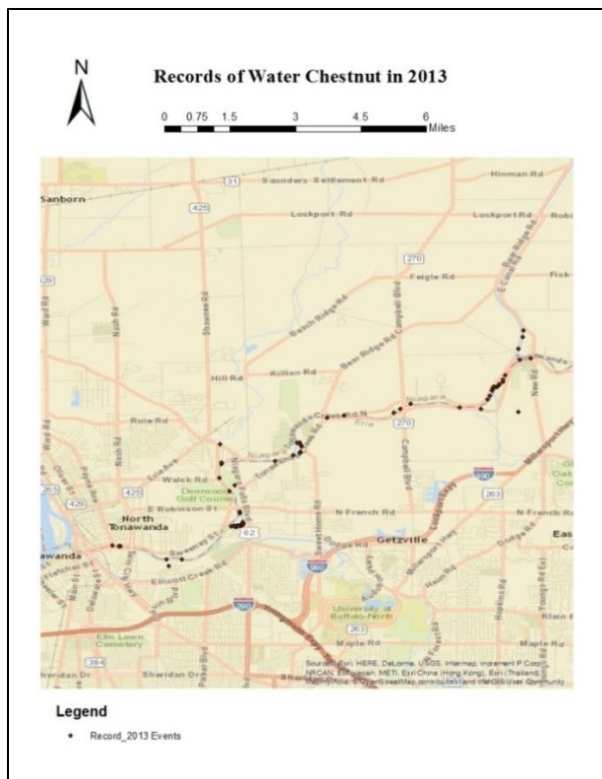
a)



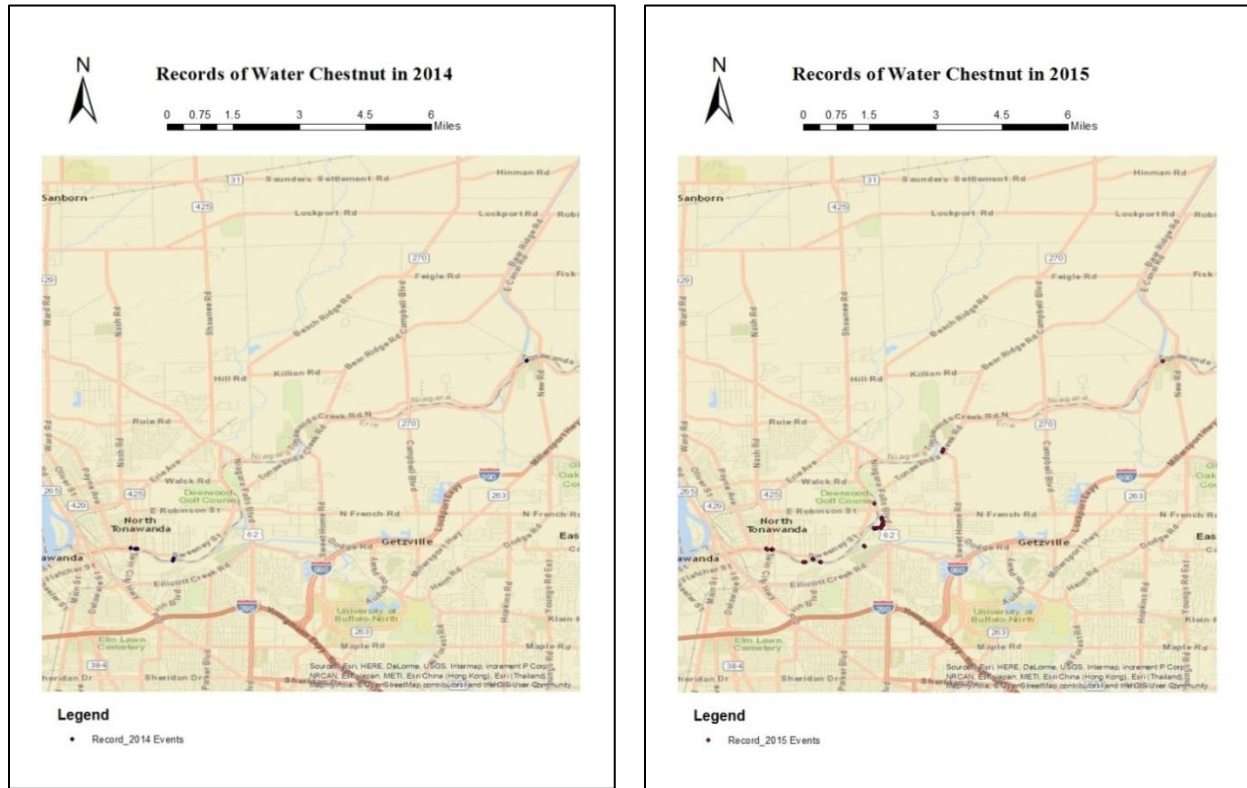
b)



c)



d)



e)

f)

Figure 8 Records of Water Chestnut in 2010~2015

The maps were based on the shapfile database provided by the Lower Great Lakes Fish and Wildlife Conservation Office

In 2016, the water chestnut records were collected by UAVs and were also showed on the map (Figure 9).

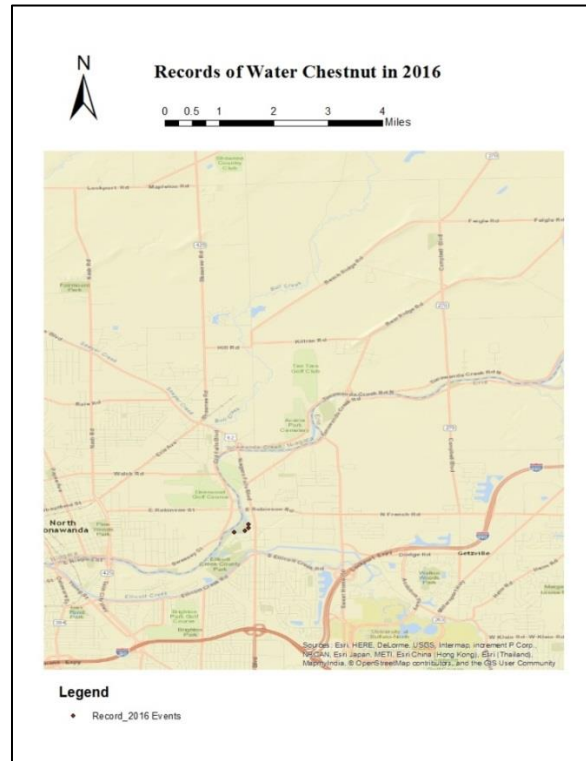


Figure 9 Records of Water Chestnut in 2016

(This map was drawn according to the drone field survey conducted by SUNY –Buffalo State College research team)

According to these maps, the physical pulling method has an efficient effect on removing water chestnut. In order to understand the annual variation intuitively, the numbers of discovered plants and pulled plants are shown in Table 1.

Table 1 Numbers of Water Chestnut During 2010 to 2016

(2010-2015 data were calculated according to the shapfile database provided by the Lower Great Lakes Fish and Wildlife Conservation Office, 2016 data were based on the field survey)

Year	Number of		
	Sites	Observed Plants	Pulled Plants
2010	288	1058	NA
2011	198	2052	1947
2012	88	555	509
2013	68	341	341
2014	6	214	214
2015	35	266	264
2016	4	4	4

---

The 4 records observed in the summer of 2016 were all found in the Ellicott Island Park (43.0303587 N, 78.8268504 W) area. There were water chestnut plants discovered in the southeast reach of Ellicott Island Park every year except 2014. In 2010, there were more than 200 water chestnut plants found in that park. In 2011, more than 800 water chestnut plants were found in this area. There were about 150 plants found in 2012 and the number reduced to around 80 in 2013. However, in 2015, the number of plants increased to more than 100 again. The two plants, which were not pulled in 2015, were also in this area, and then these two plants regrew in 2016 and two more plants added.

The Amherst Veterans Canal Park (43.0626986 N, 78.8050533 W) is another hot spot of water chestnut growing. In 2010 and 2011, there were around 50 plants in this area. However, there were around 100 plants found in 2012. In 2013, there were still about 80 plants in this area. Besides these two parks, the water chestnut intensively grew in several docking sites along the creek, in particular in the two docking sites near Twin Cities Memorial Highway.

The Ellicott Island Park is located between transect 4 and 5. The Amherst Veterans Canal Park is located between transect 3 and 4. The docking sites near Twin Cities Memorial Highway are located between transect 5 and 6. Table 2 shows that these reaches grow more water chestnut than the other reaches. The reach between transect 3 and 4 has the largest water chestnut population.

Table 2 Distribution of Water Chestnut During 2010 to 2016

(2010-2015 data were calculated according to the shapfile database provided by the Lower Great Lakes Fish and Wildlife Conservation Office, 2016 data were based on the field survey)

Year	Reach					
	Transect 1~2	Transect 2~3	Transect 3~4	Transect 4~5	Transect 5~6	Transect 6~7
2010	16	224	304	402	110	2
2011	56	112	1418	299	167	0
2012	112	98	206	21	118	0
2013	65	6	199	24	50	1
2014	4	0	0	0	210	0
2015	4	0	158	25	79	0
2016	0	0	0	4	0	0

## 4.2 Results of Land Use and Land Cover Analyses

### 4.2.1 Unsupervised Classification



Figure 10 The Entire Study Area (After Mosaic Process in ERDAS Imagine)

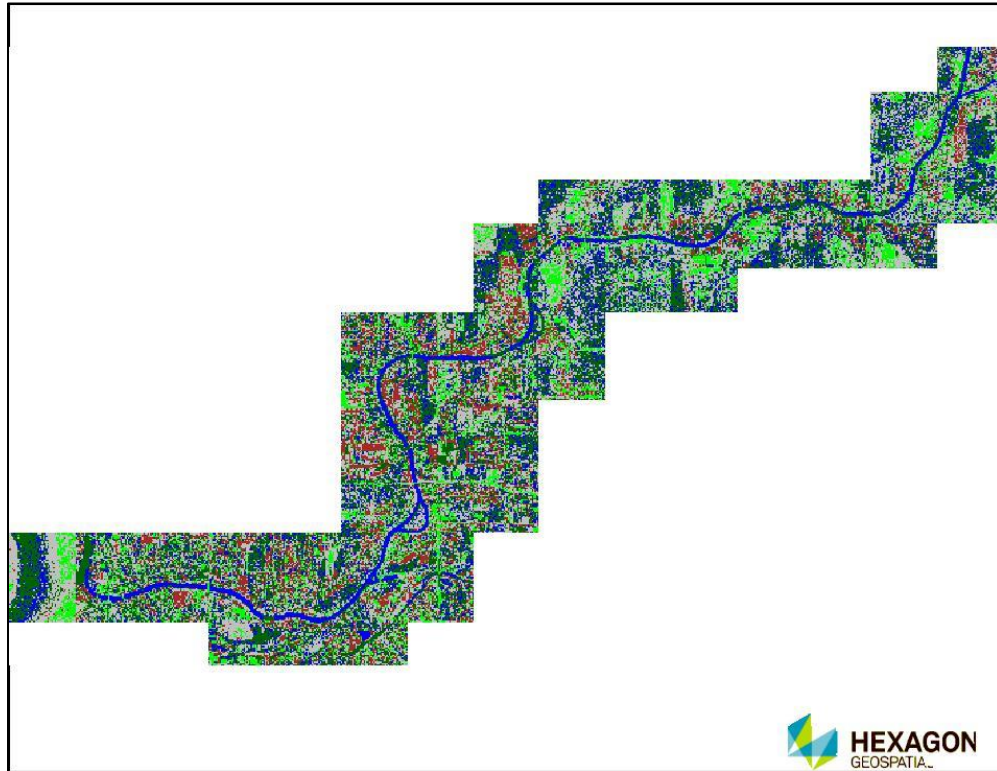


Figure 11 The Result of Unsupervised Classification

The mosaicked image of entire study area is shown in Figure 10. The Niagara Falls Boulevard is the boundary dividing urban and rural areas. Both of the two parks growing many water chestnut plants are near the Niagara Falls Boulevard. Although the two parks are covered by vegetation, they are popular areas for recreational activities, such as picnics. In the meantime, many local people like to row boats in these two parts of the waterway. The two docking sites near Twin Cities Memorial Highway are in the classified urban areas.

In the result image of unsupervised classification (Figure 11), blue pixels represent waterbody, green pixels represent lawn, dark green pixels represent forest, grey pixels represent bare soil, and brown pixels represent urban areas that are occupied by buildings, roads, etc. According to Figure 11, the upstream surrounding, which is rural areas, has more large blocks of lawn and



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forest. The total area of lawn in urban areas is not dramatically decreased from that in rural areas, but the lawn is broken up by the urban built-up (brown) patches.

#### 4.2.2 NDVI

The calculation result of NDVI should be inside the mathematical set  $[-1, 1]$ . According to the definition of NDVI, the result of the area covered by green vegetation should be more than 0; the result of waterbody should be less than 0; the result of bare soil should be equal to 0. Greyscale images were developed following the rule: 1=white, -1=black, and then evenly divided grey scale between black and white (Figure 12).

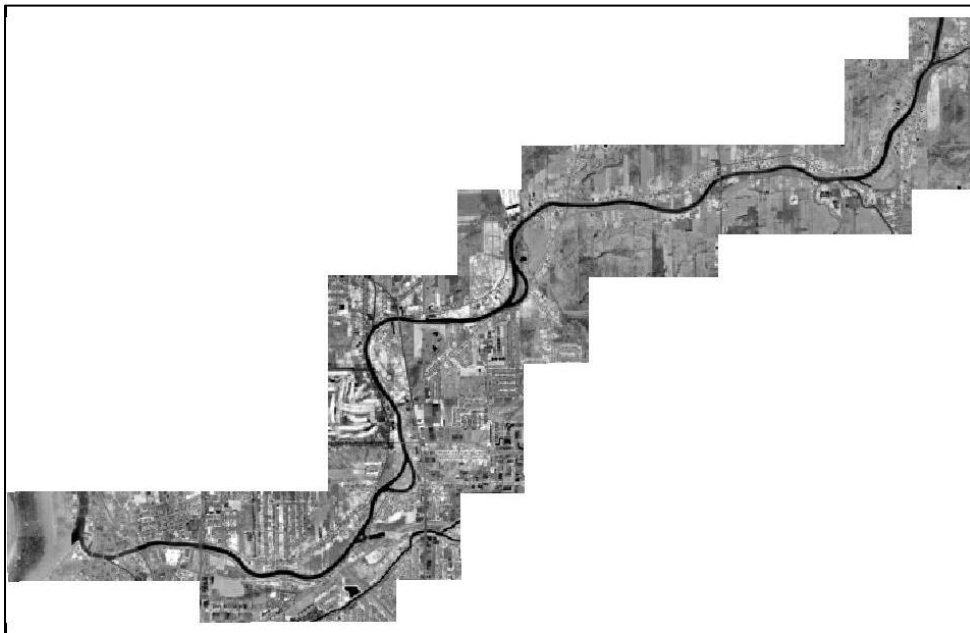


Figure 12 The Result of NDVI Analysis

According to Figure 12, there are several patches of vegetation reflecting most near-infrared light in the mid-stream area. This is exactly the place growing the largest amount of water chestnut plants. The water chestnut plants in this area are also the most stubborn and occupied the longest time. The NDVI result approved the result of unsupervised classification that the vegetation covered area in urban regions is not dramatically decreased from that in rural areas.

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## **4.3 Results of Habitat Condition Analyses**

To analyze the environmental regulating effect of the lower Tonawanda Creek on water chestnut abundance, we applied spatial interpolation based on temperature and relative humidity data at 0m and 12m altitude respectively. In addition, we plotted and analyzed temperature and relative humidity differences for each of the transects.

### **4.3.1 Analyses of Temperature**

The surface (0m) and 12m-height temperature interpolation maps are shown in Figures 13-19.





a)

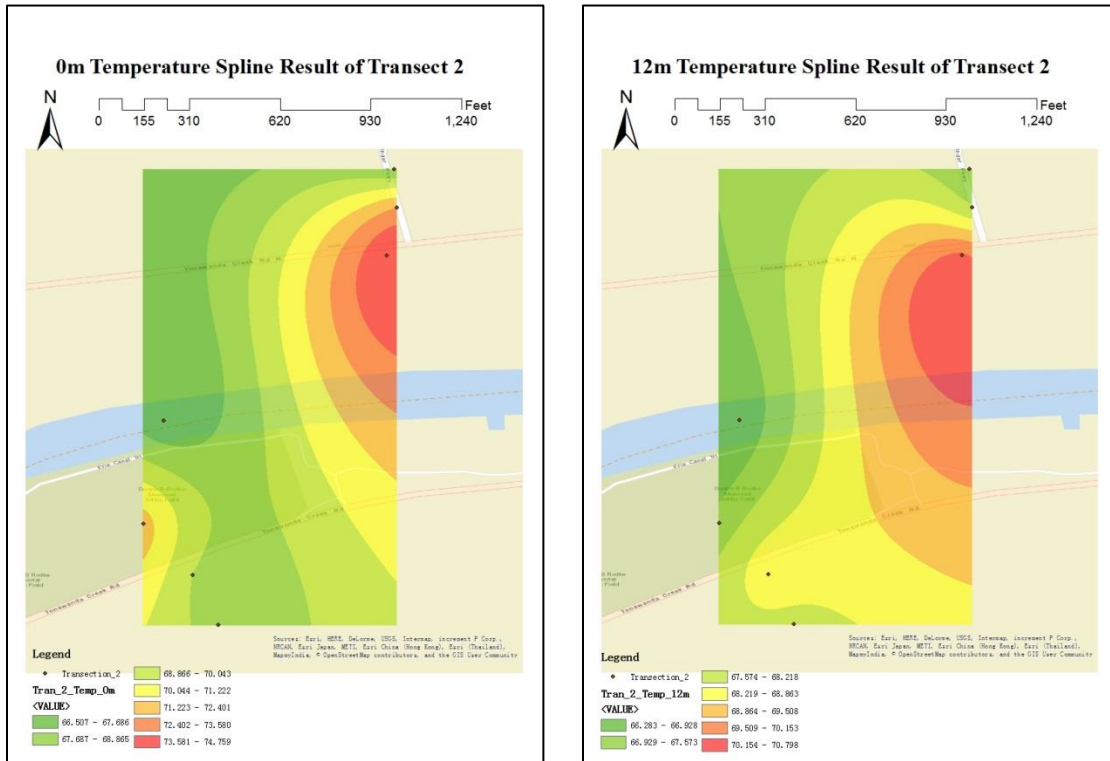
b)



c)

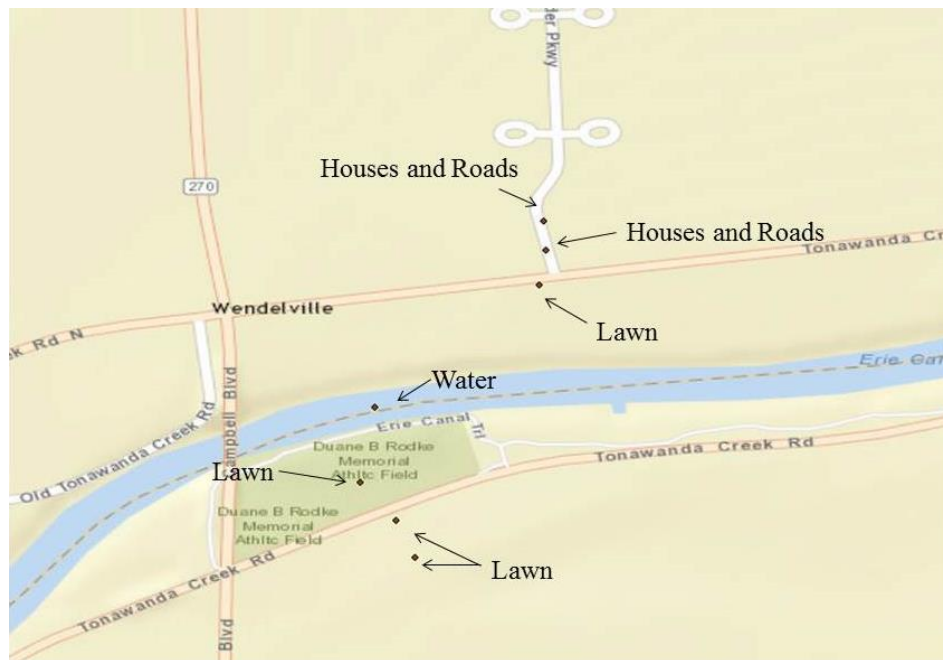
Figure 13 Temperature Interpolation of Transect 1 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 1

(Collected from 10:10 am to 10:30 am on August 1<sup>st</sup>, 2016. 43.084167 N, 78.734167 W)



a)

b)



c)

Figure 14 Temperature Interpolation of Transect 2 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 2

(Collected from 11:20 am to 11:50 am on August 1<sup>st</sup>, 2016. 43.070121 N, 78.76892 W)

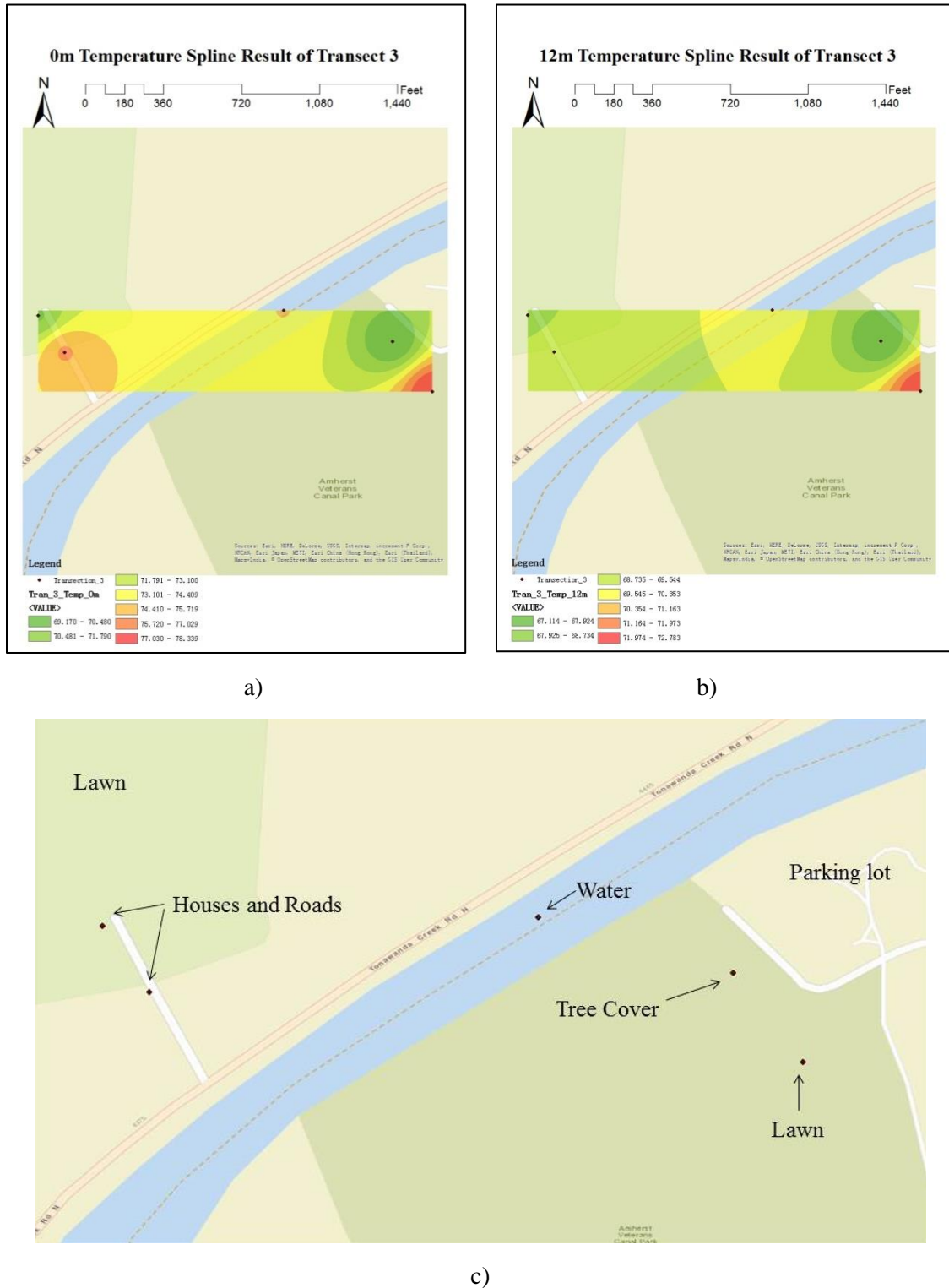
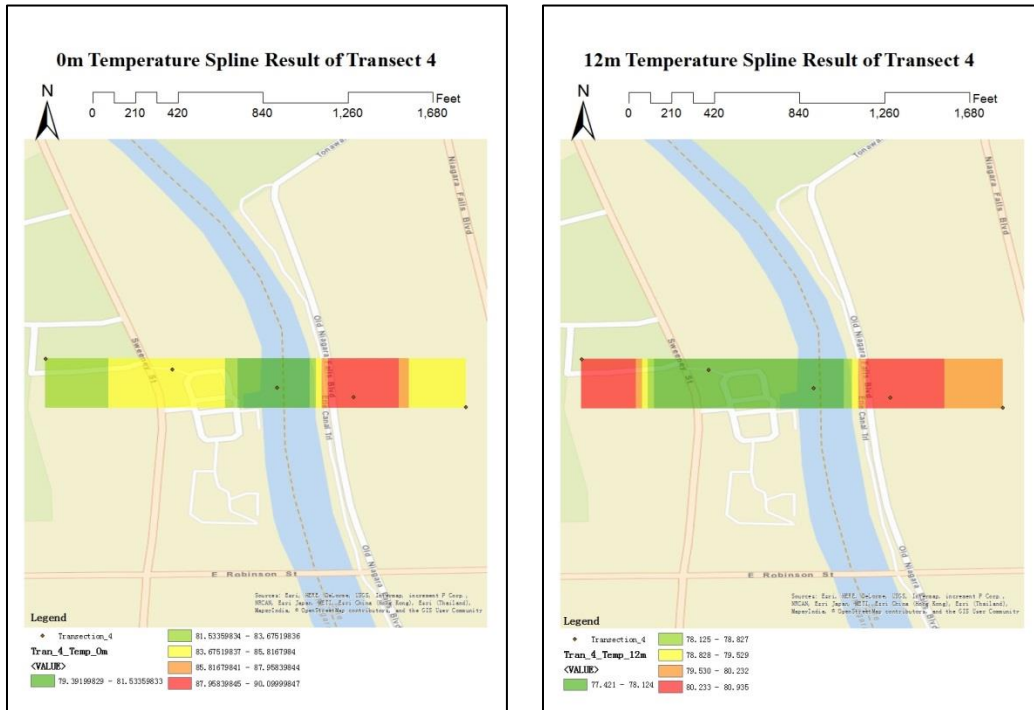


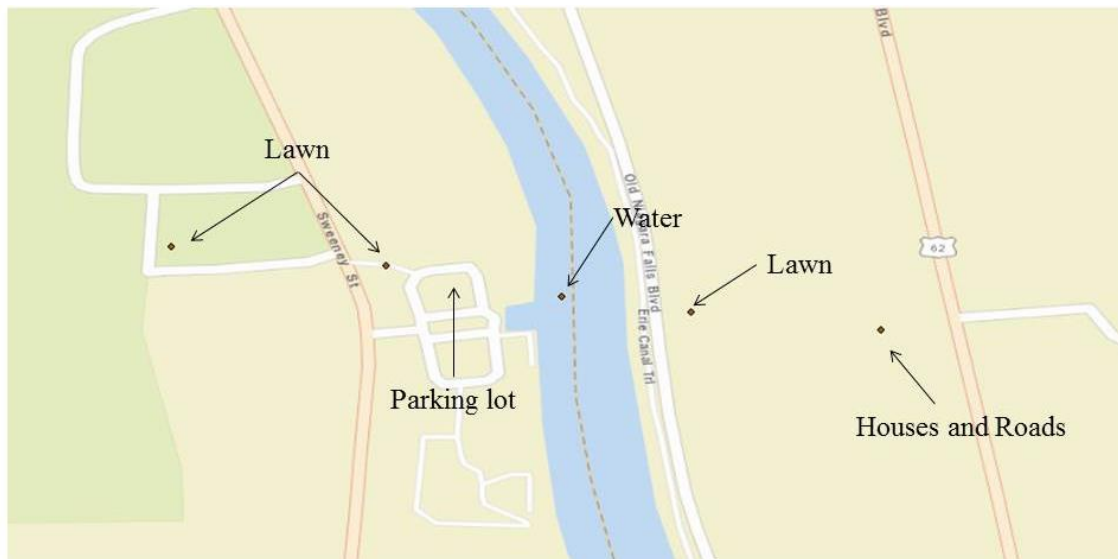
Figure 15 Temperature Interpolation of Transect 3 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 3

(Collected from 1:30 pm to 2:10 pm on August 1<sup>st</sup>, 2016. 43.06488 N, 78.80387 W)



a)

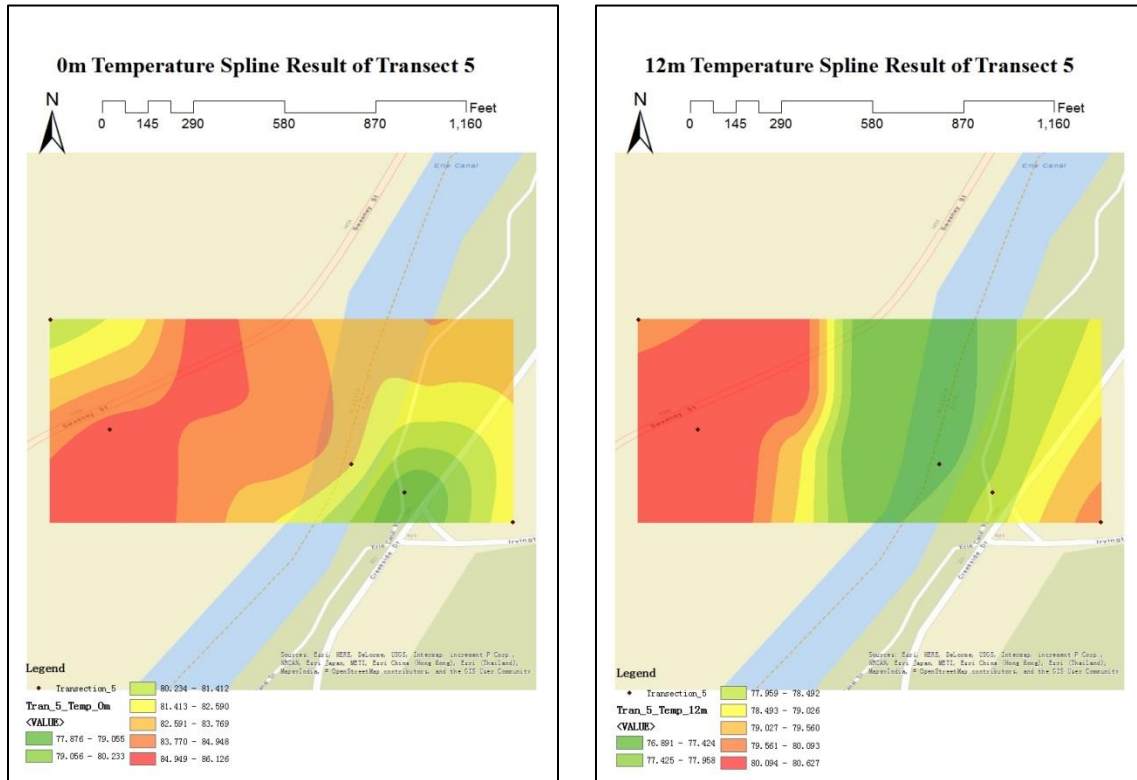
b)



c)

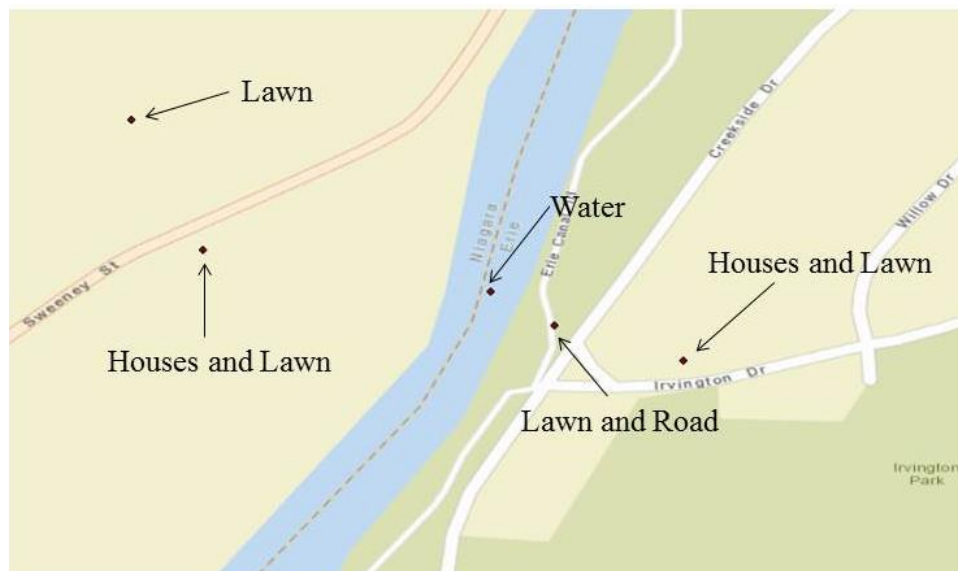
Figure 16 Temperature Interpolation of Transect 4 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 4

(Collected from 2:50 pm to 3:15 pm on August 1<sup>st</sup>, 2016. 43.038506 N, 78.82682 W)



a)

b)

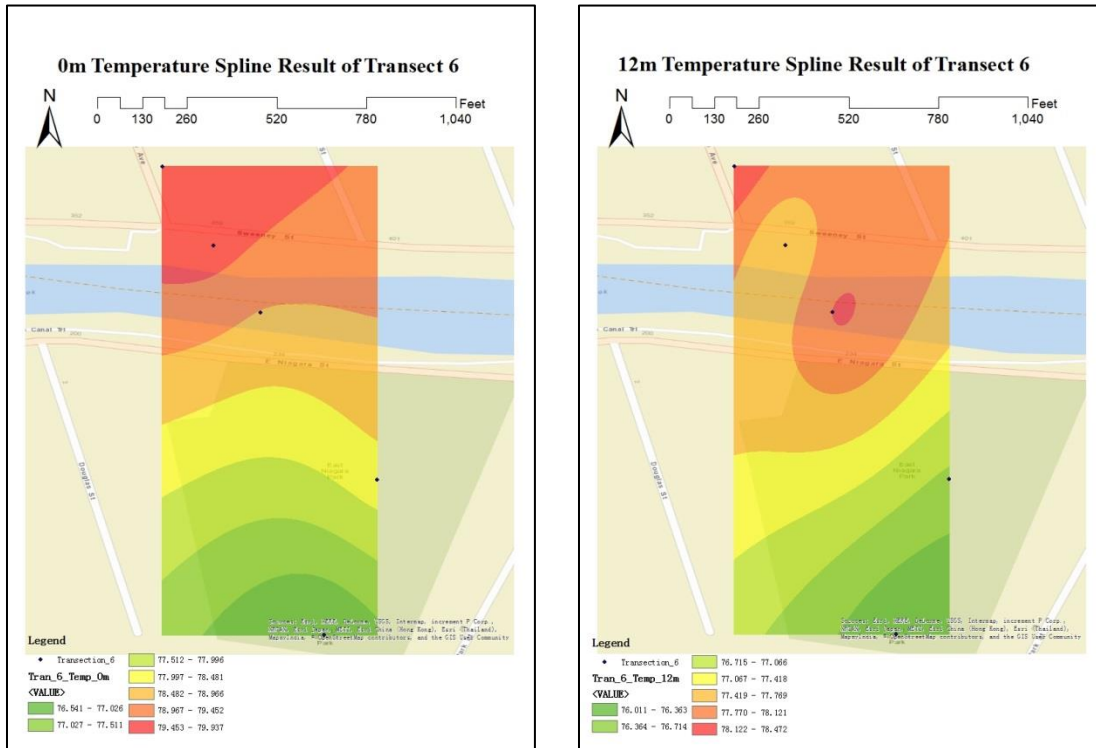


c)

Figure 17 Temperature Interpolation of Transect 5 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 5

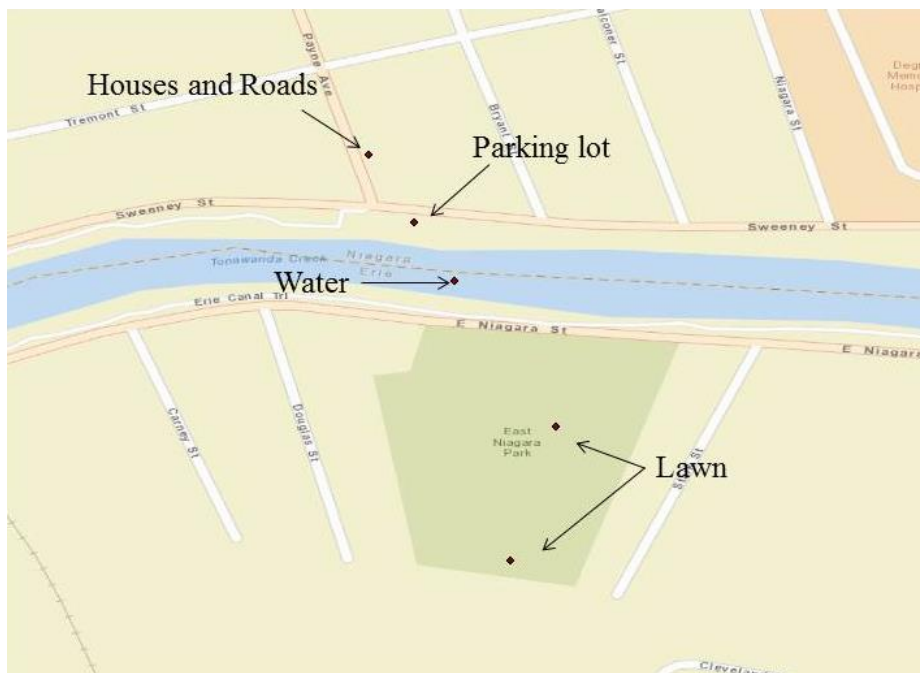
(Collected from 11:00 am to 11:25 am on August 2<sup>nd</sup>, 2016. 43.038506 N, 78.82682 W)





a)

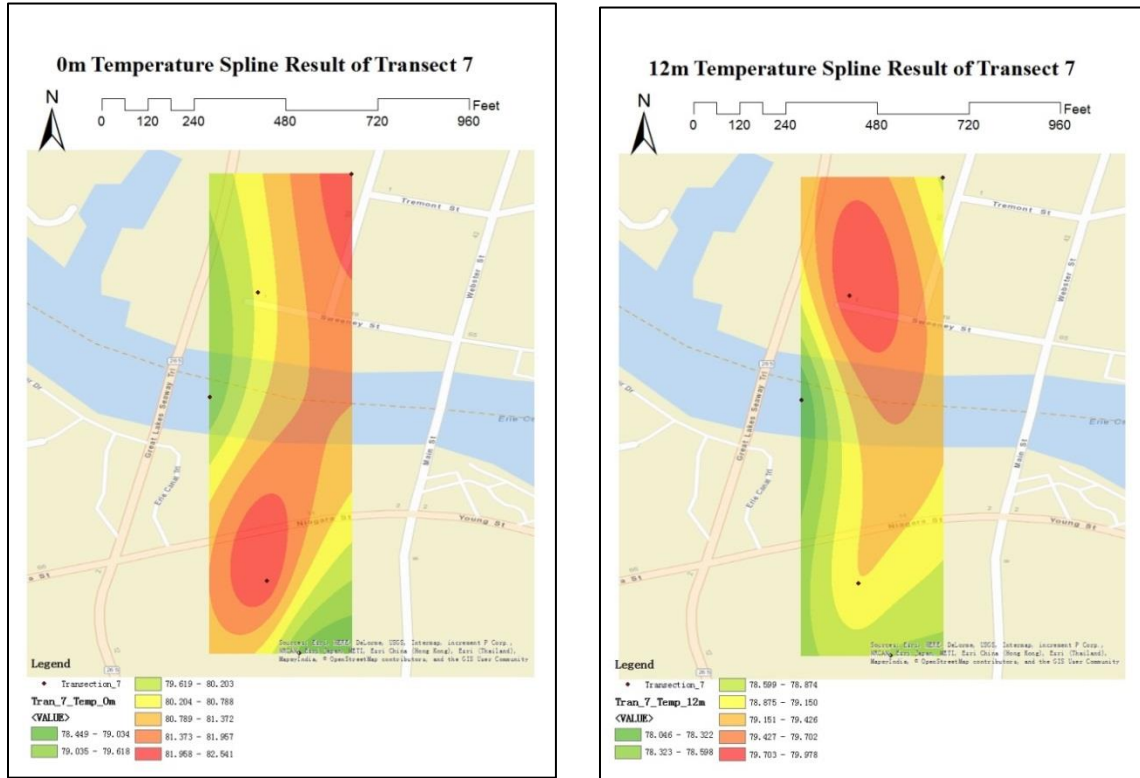
b)



c)

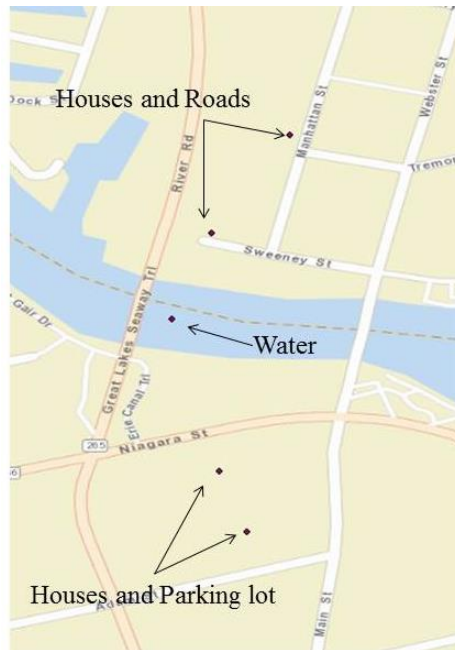
Figure 18 Temperature Interpolation of Transect 6 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 6

(Collected from 12:50 pm to 1:20 pm on August 2<sup>nd</sup>, 2016. 43.023158 N, 78.866547 W)



a)

b)



c)

Figure 19 Temperature Interpolation of Transect 7 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 7

(Collected from 1:45 pm to 2:20 pm on August 2<sup>nd</sup>, 2016. 43.021711 N, 78.879701 W)

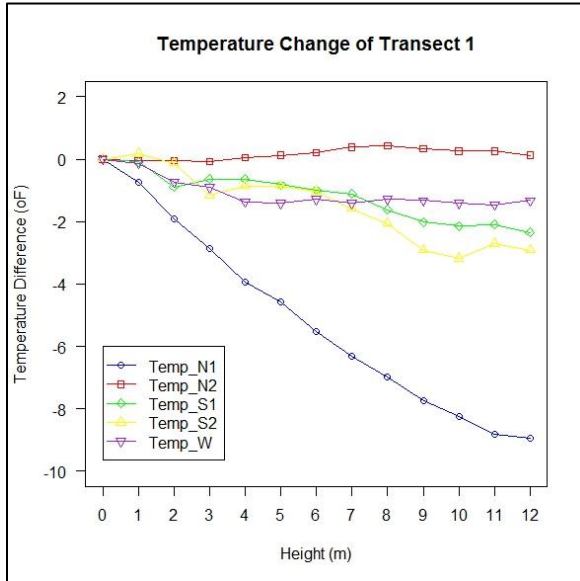
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According to the 0m interpolation maps, the temperature regulating effect in the horizontal direction is not very strong. The forest area has an average lower air temperature than that on the water surface in the creek; the urban area has an average higher temperature than that on the water surface in the creek.

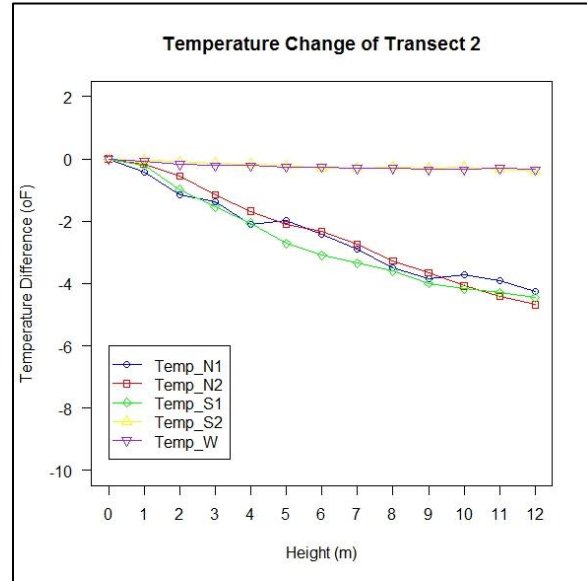
The environmental regulating capability of water at 0m is not strong enough to affect the distribution of temperature. However, when the height increased to 12m, the temperature distributions of transects 1 through 5 show the stronger regulating capabilities. In Figures 13-17, the temperature above the creek is lower than the surrounding areas, which should be caused by the endothermic effect of water evaporation. In Figure 19, the temperature above the creek is neither the lowest nor the highest. The Figure 18 also shows the similar situation. Transect 6 shows different conditions since there is a large patch of lawn near the southern river bank. Transect 7 is also located in the urban area, but Figures 19 shows lower temperature above the creek and higher temperature on the banks. That is because transect 7 is located near the mouth of the Tonawanda Creek and is very close to the Niagara River, which is a large waterbody. The Niagara River may play the stronger role than the human made utilities in regulating environmental conditions.

In the vertical direction, the changes of temperature of transects are shown in Figure 20.

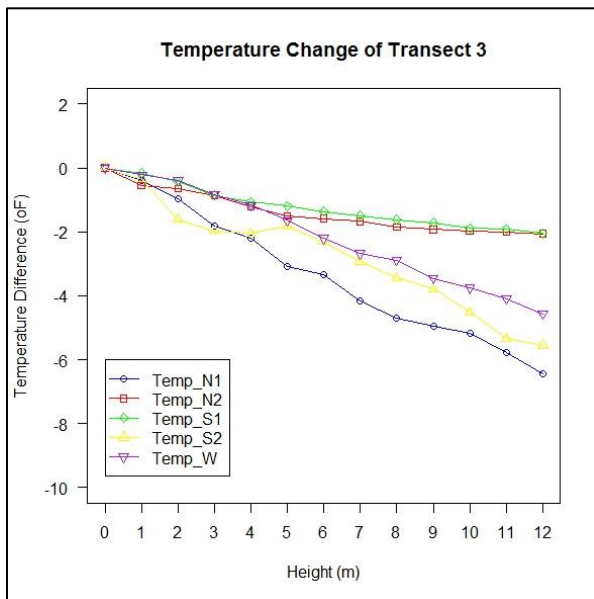




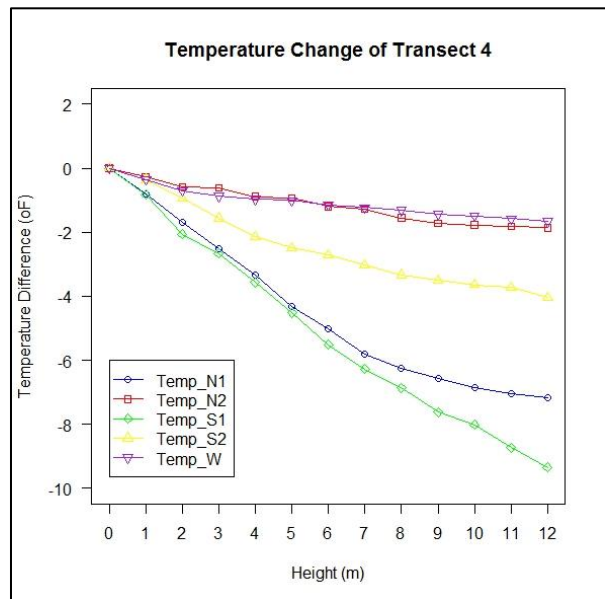
a)



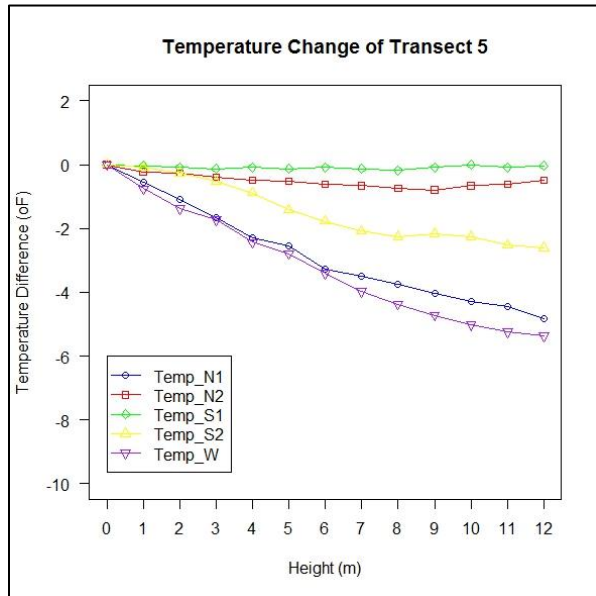
b)



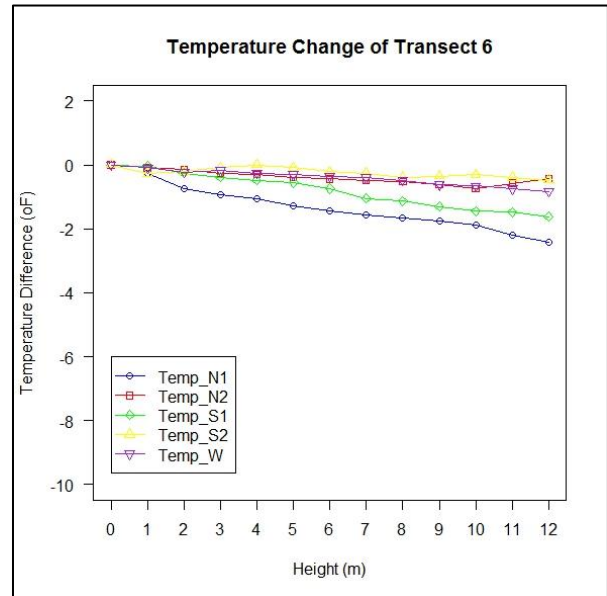
c)



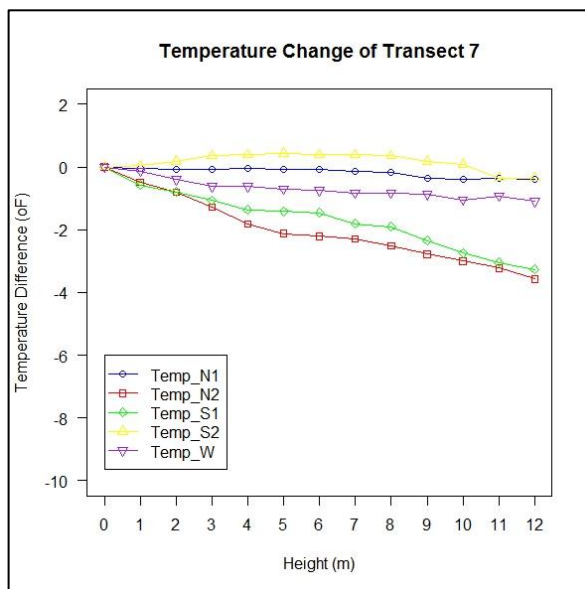
d)



e)



f)



g)

“Temp\_W” represents the site above the center of the creek; “Temp\_N1” represents the site which is the nearer one from the north bank of the creek; “Temp\_N2” represents the farther site from the north bank; “Temp\_S1” represents the site which is the nearer one from the south bank of the creek; “Temp\_S2” represents the farther site from the south bank. Temperature difference means the difference between the temperature of the specific height and the temperature of 0m (surface).

Temperature data were collected: a) from 10:10 am to 10:30 am on August 1<sup>st</sup>, 2016; b) from 11:20 am to 11:50 am on August 1<sup>st</sup>, 2016; c) from 1:30 pm to 2:10 pm on August 1<sup>st</sup>, 2016; d) from 2:50 pm to 3:15 pm on August 1<sup>st</sup>, 2016; e) from 11:00 am to 11:25 am on August 2<sup>nd</sup>, 2016; f) from 12:50 pm to 1:20 pm on August 2<sup>nd</sup>, 2016; g) from 1:45 pm to 2:20 pm on August 2<sup>nd</sup>, 2016.

The location of the water center site of each transect is: a) 43.084167 N, 78.734167 W; b) 43.070121 N, 78.76892 W; c) 43.06488 N, 78.80387 W; d) 43.038506 N, 78.82682 W; e) 43.026948 N, 78.831549 W; f) 43.023158 N, 78.866547 W; g) 43.021711 N, 78.879701 W.

Figure 20 Temperature Changes of Transects 1-7.

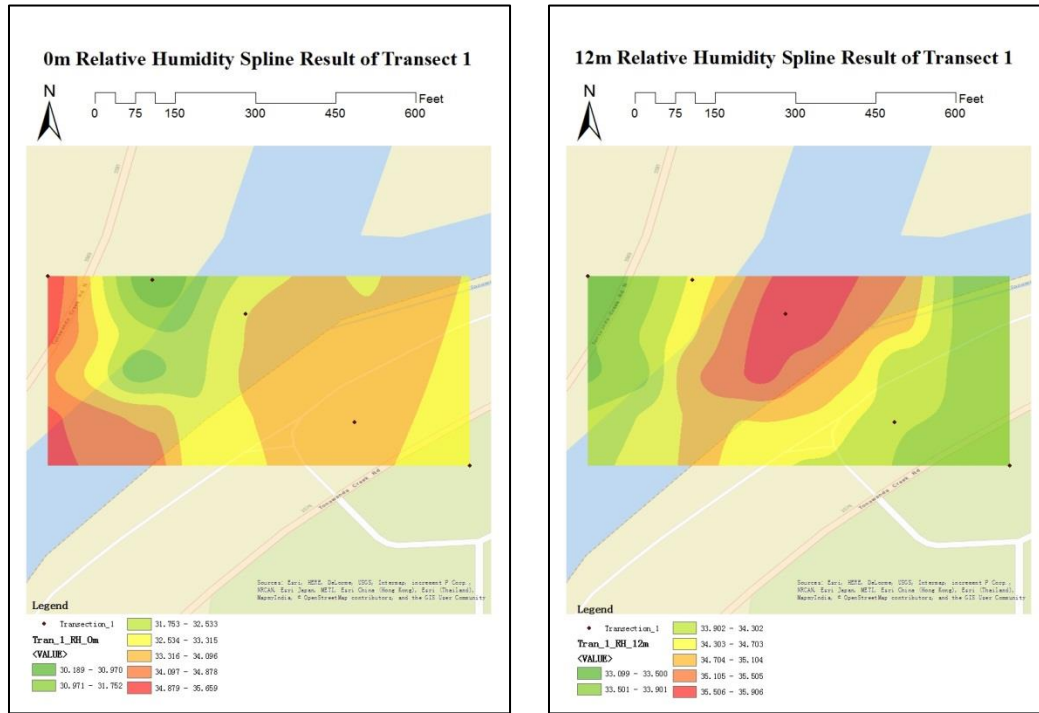
According to the line graph plots, as the altitude increasing, the temperature decreases in general. However, different sites have different intensities of temperature decrease. Except in transects 3 and 5, the temperature above the water surface in the creek decreases slowly, which suggests the water moderate effect exists at the micro-climatic environment. The temperature differences in

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transects 6 and 7 are smaller than the other five transects, which could be because these two transects are located in the urban areas.

#### **4.3.2 Analyses of Relative Humidity**

The relative humidity (RH) data on the surface (0m) are interpolated showing in Figures 21-27.



a)

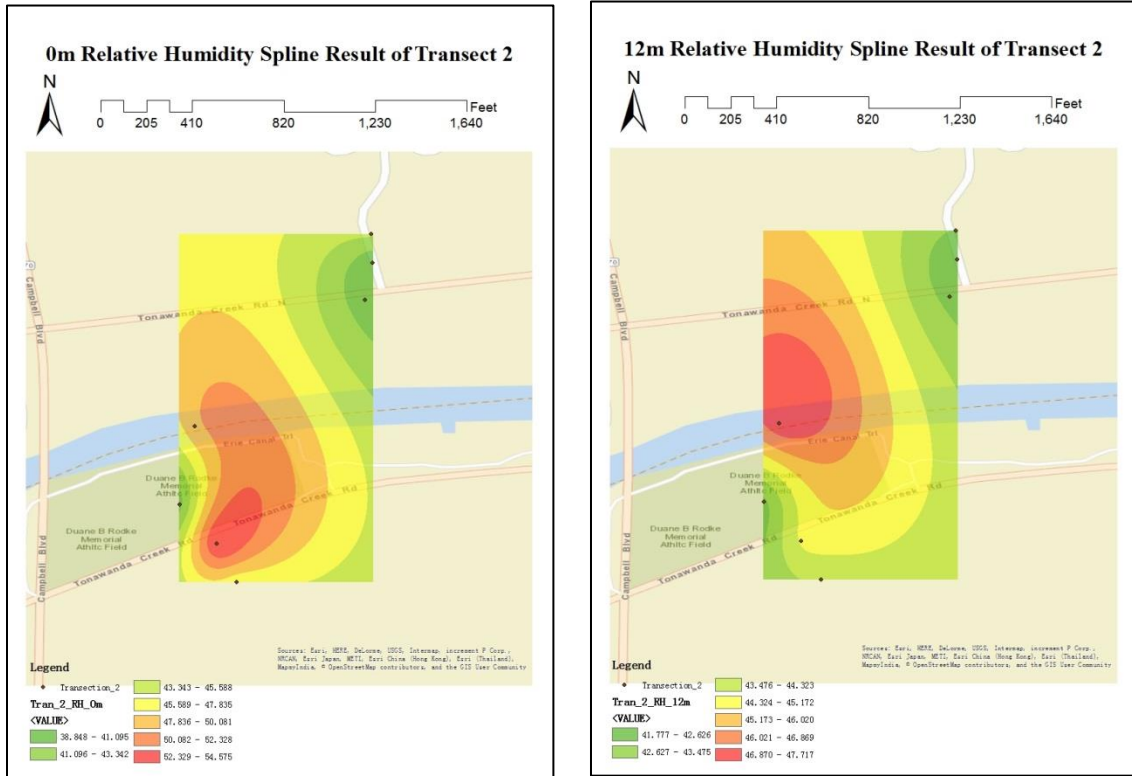
b)



c)

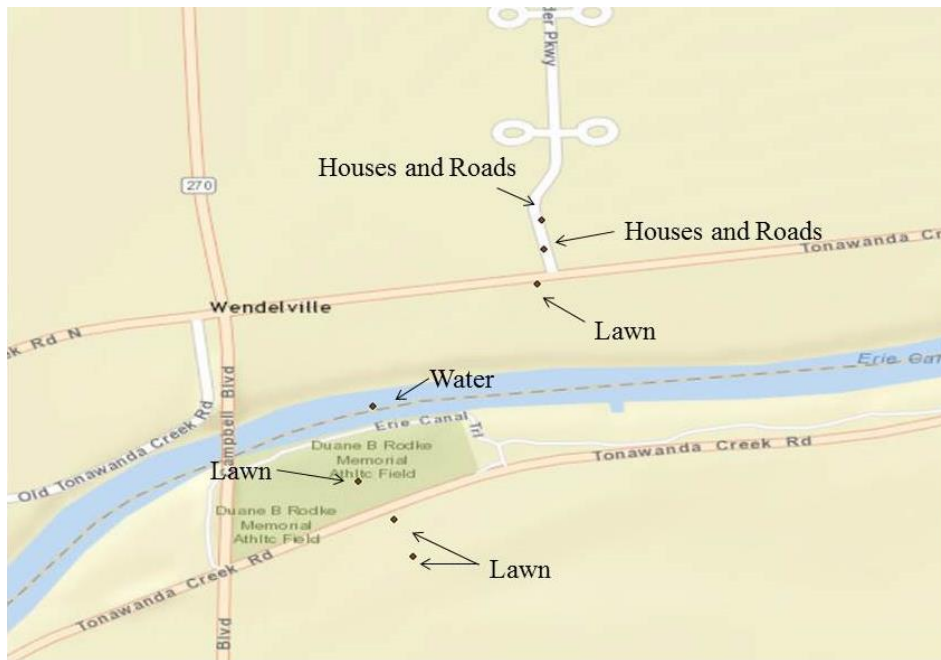
Figure 21 Relative Humidity Interpolation of Transect 1 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 1

(Collected from 10:10 am to 10:30 am on August 1<sup>st</sup>, 2016. 43.084167 N, 78.734167 W)



a)

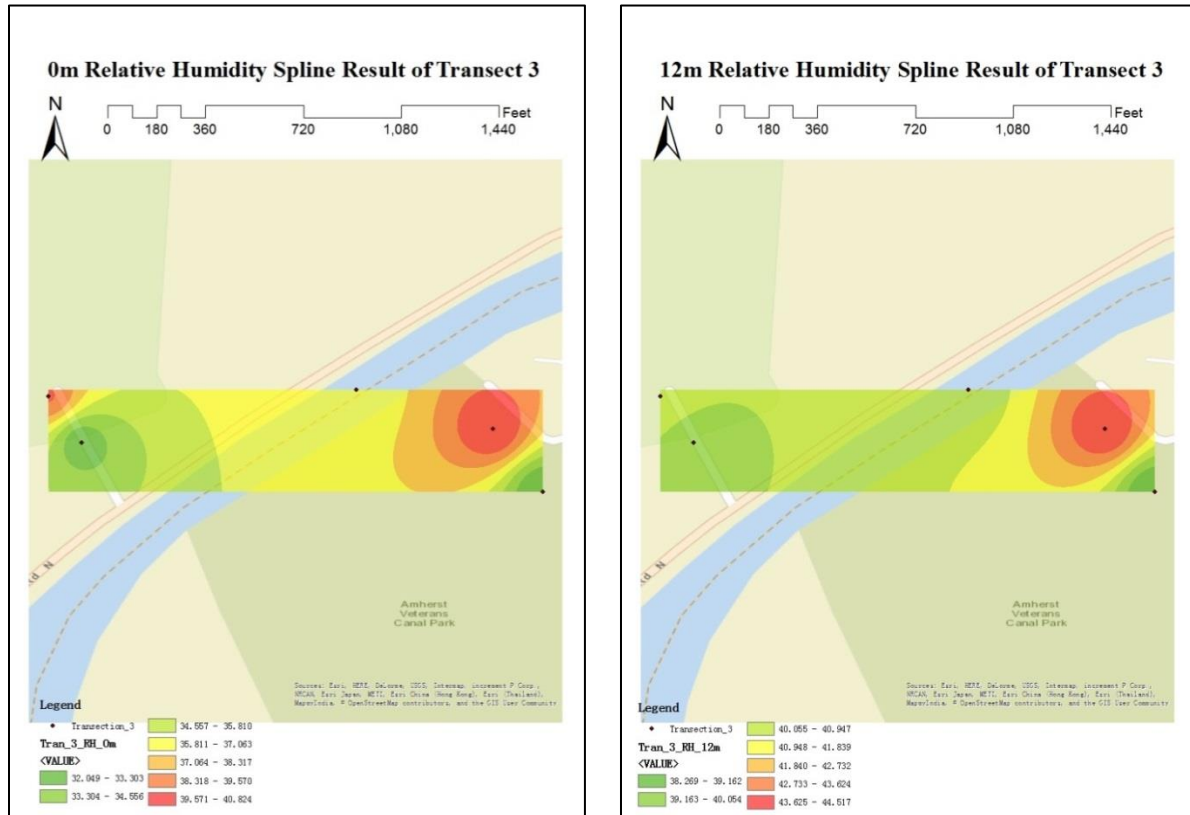
b)



c)

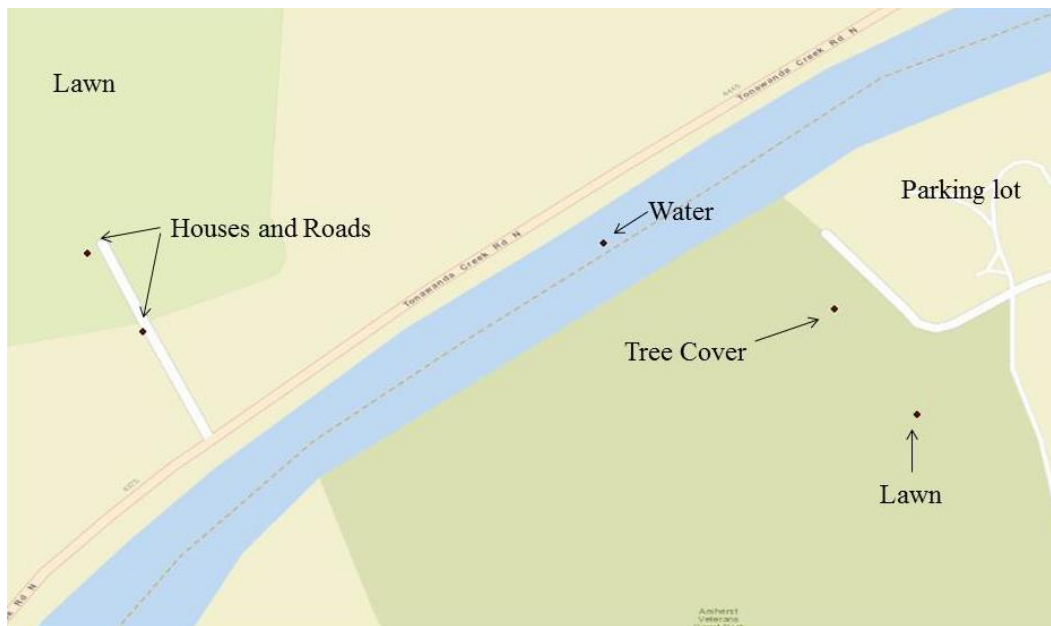
Figure 22 Relative Humidity Interpolation of Transect 2 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 2

(Collected from 11:20 am to 11:50 am on August 1<sup>st</sup>, 2016. 43.070121 N, 78.76892 W)



a)

b)



c)

Figure 23 Relative Humidity Interpolation of Transect 3 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 3

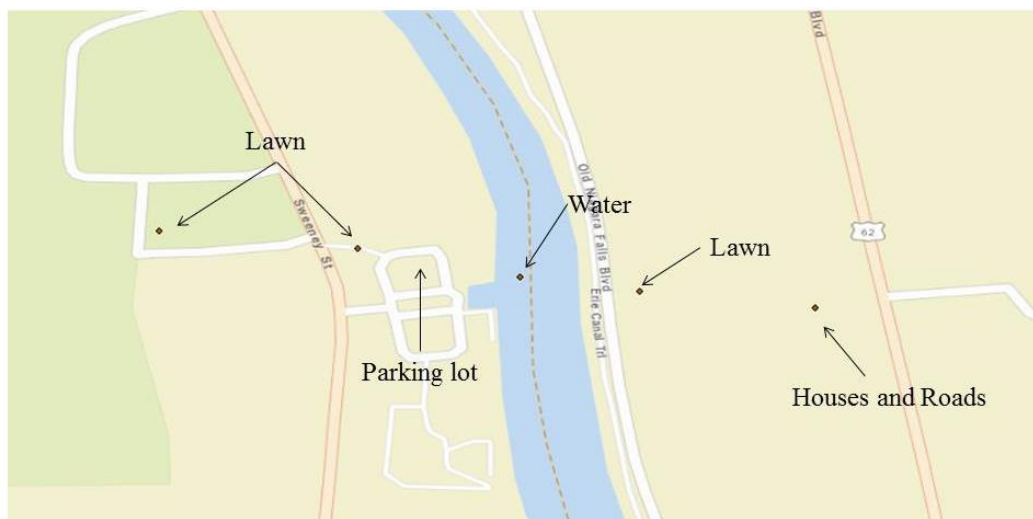
(Collected from 1:30 pm to 2:10 pm on August 1<sup>st</sup>, 2016. 43.06488 N, 78.80387 W)





a)

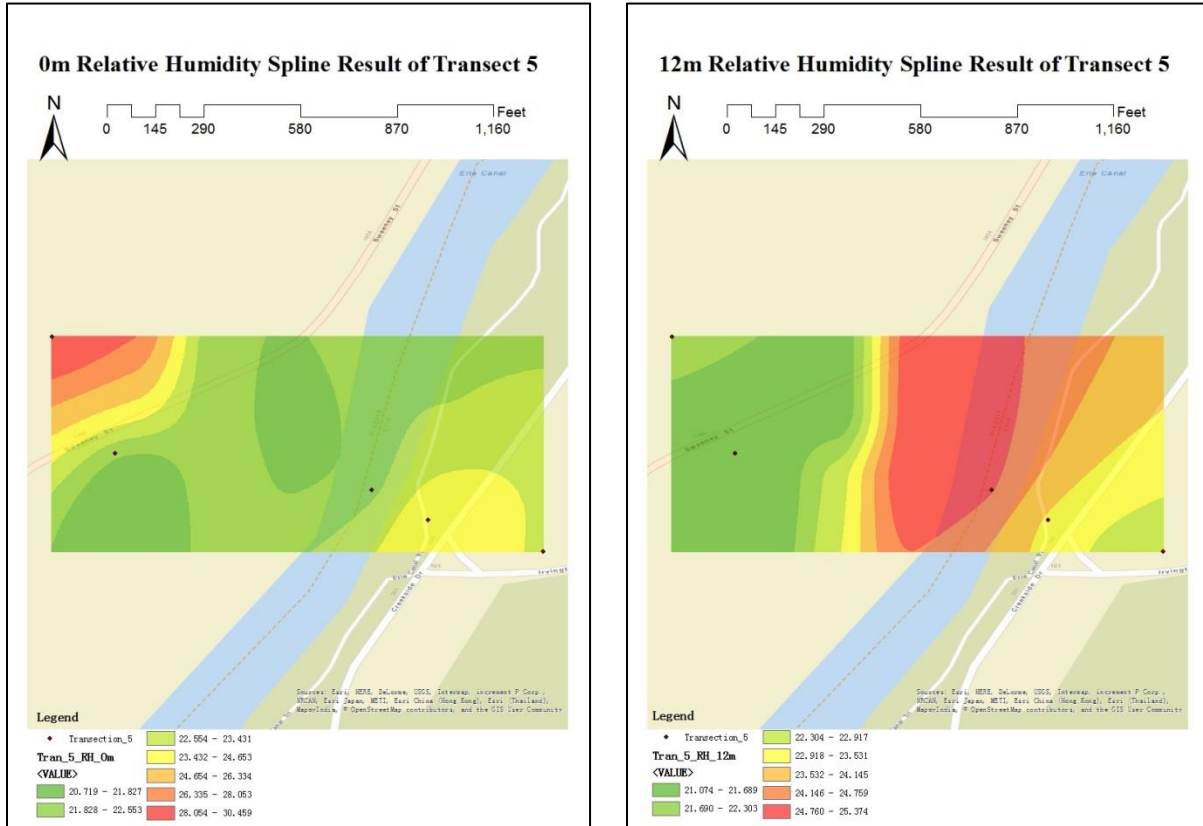
b)



c)

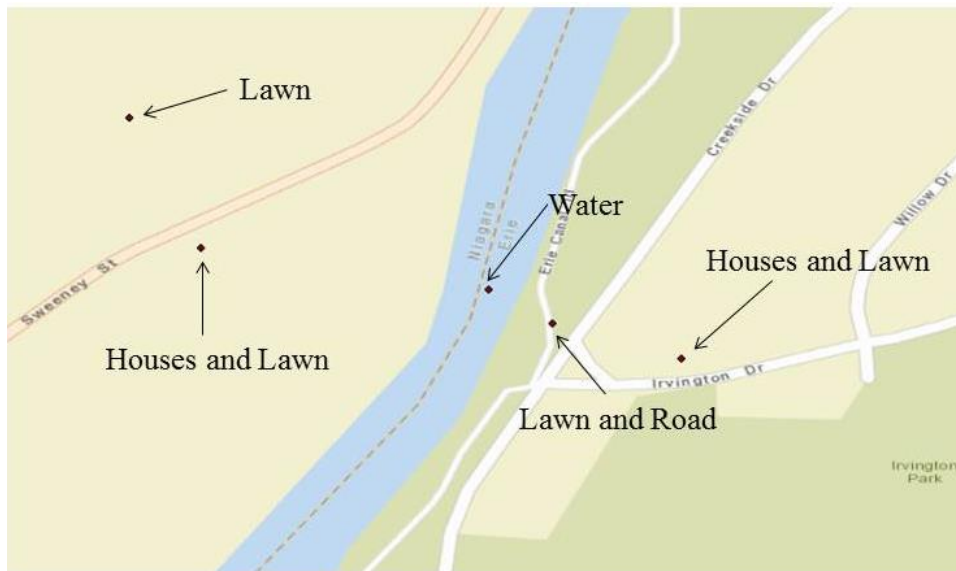
Figure 24 Relative Humidity Interpolation of Transect 4 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 4

(Collected from 2:50 pm to 3:15 pm on August 1st, 2016. 43.038506 N, 78.82682 W)



a)

b)

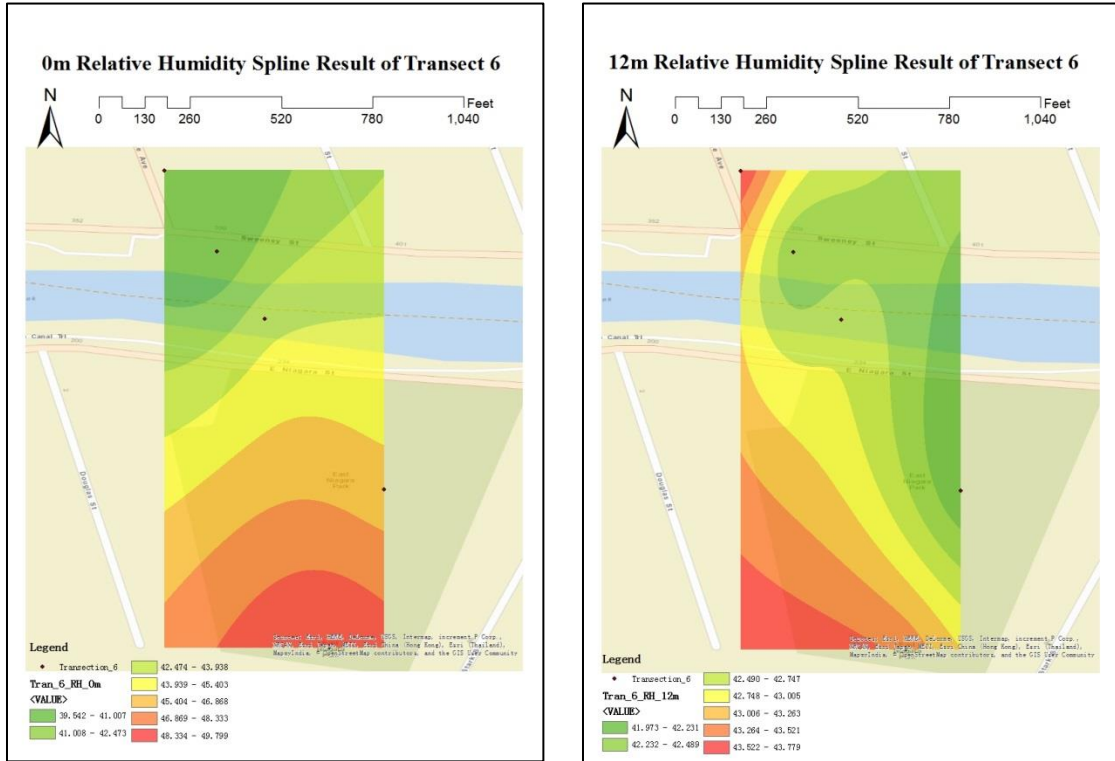


c)

Figure 25 Relative Humidity Interpolation of Transect 5 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 5

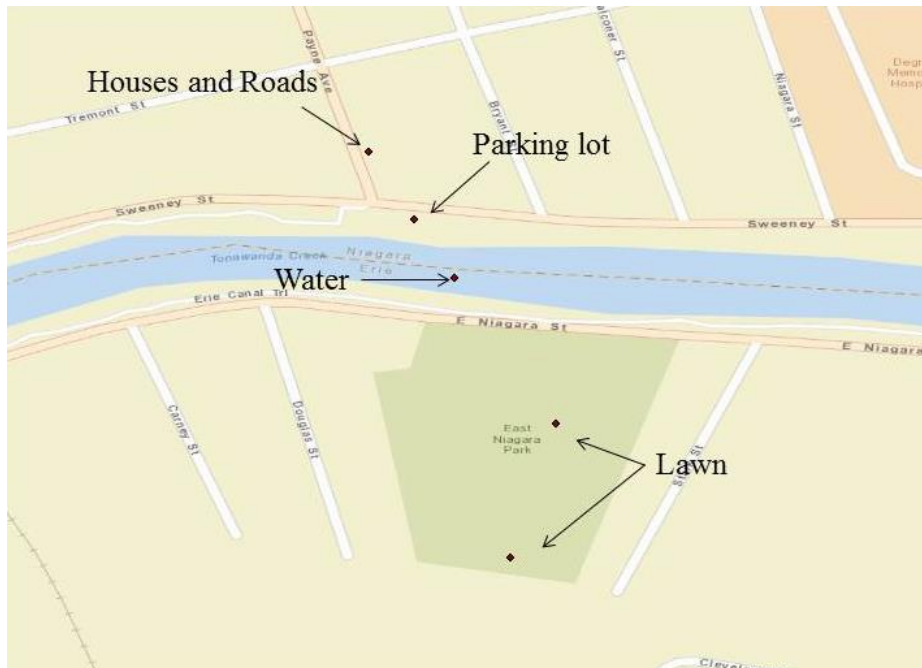
(Collected from 11:00 am to 11:25 am on August 2nd, 2016. 43.038506 N, 78.82682 W)





a)

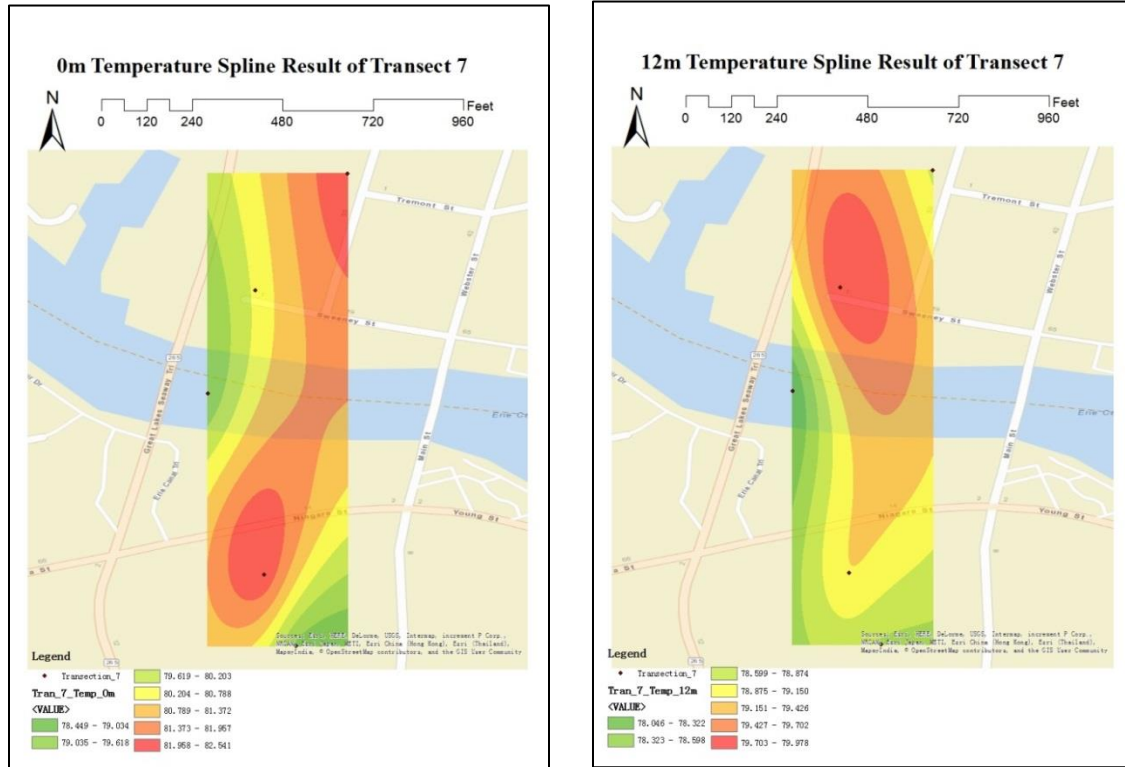
b)



c)

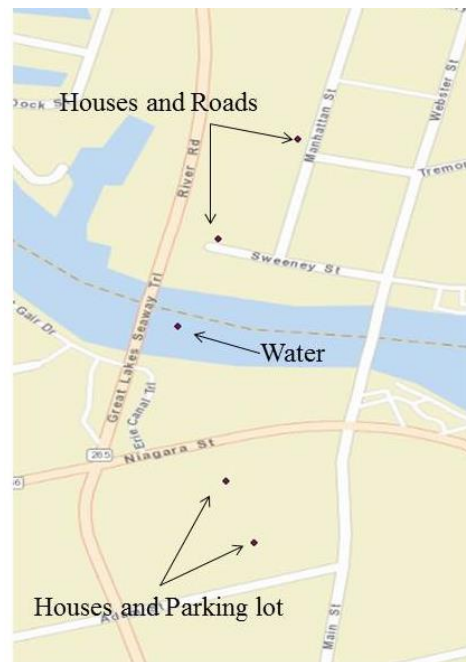
Figure 26 Relative Humidity Interpolation of Transect 6 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 6

(Collected from 12:50 pm to 1:20 pm on August 2nd, 2016. 43.023158 N, 78.866547 W)



a)

b)



c)

Figure 27 Relative Humidity Interpolation of Transect 7 at a) surface (0m); b) 12m. c) Surrounding LULC of Transect 7

(Collected from 1:45 pm to 2:20 pm on August 2nd, 2016. 43.021711 N, 78.879701 W)

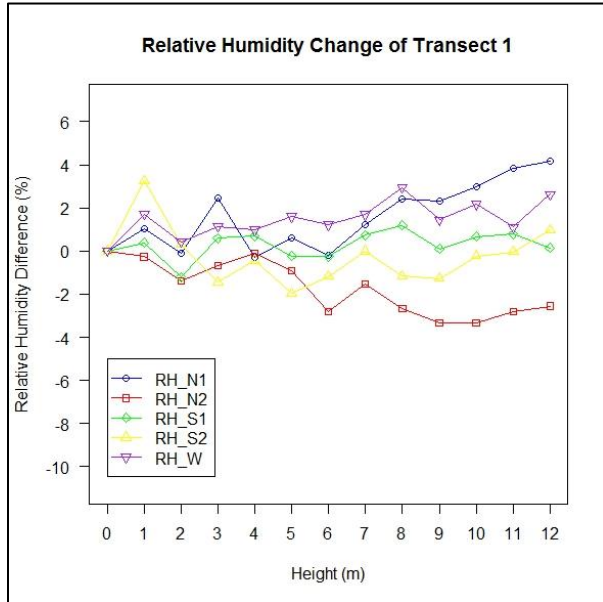
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According to the above figures, the surface relative humidity data above the creek are higher than the data in the surrounding areas in transects 1, 2, 3, 4 and 7. By contrast, in transects 5 and 6, the highest relative humidity records are not above the creek. Field measurements of this research cannot suggest that the relative humidity on the ground decreases from the water surface at the creek to the inland areas. The ground environment at the surveying time might be influenced by other climatic factors, such as wind.

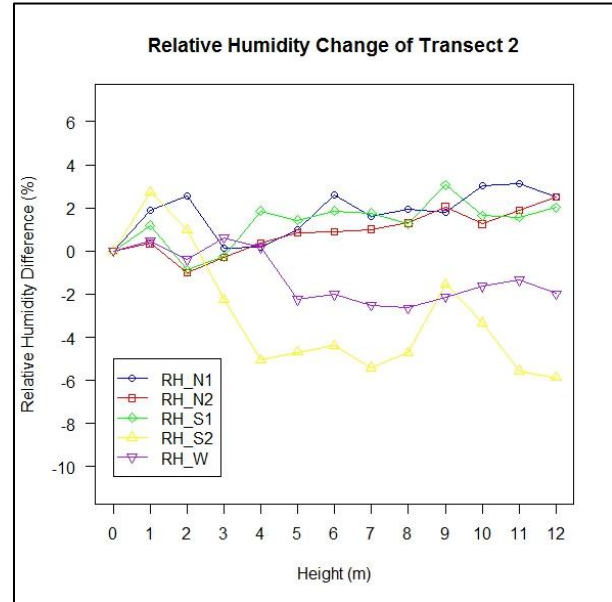
At the altitude of 12m, transects 1, 2, 3, 4, 5 and 7 show more typical regularities of horizontal changes of relative humidity, which the highest relative humidity records are above the water surface in the creek. However, transect 6 shows different pattern of changes in the horizontal direction. This could be caused by the lawn evapotranspiration impact near the southern bank of transect 6.

In summary, the interpolations of relative humidity at different altitudes along different transects show that water surface is the major land cover type to influence the distributions of relative humidity. Vegetation land cover is the second strongest impact factor to relative humidity distributions.

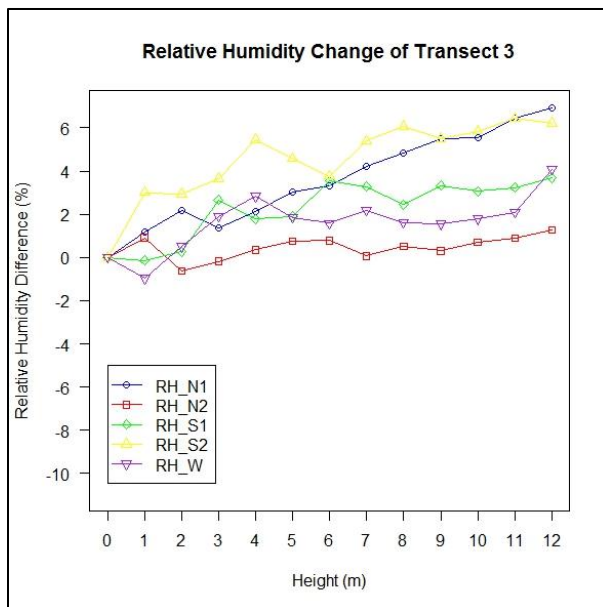
On the vertical direction, the changes of relative humidity along each transect are shown in Figures 28.



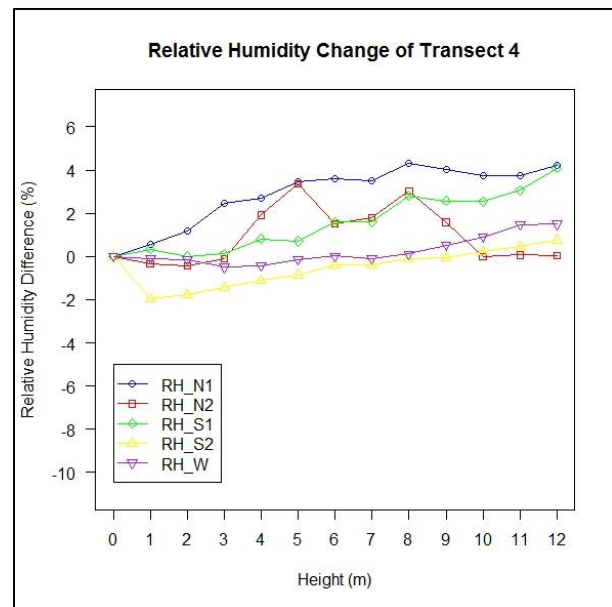
a)



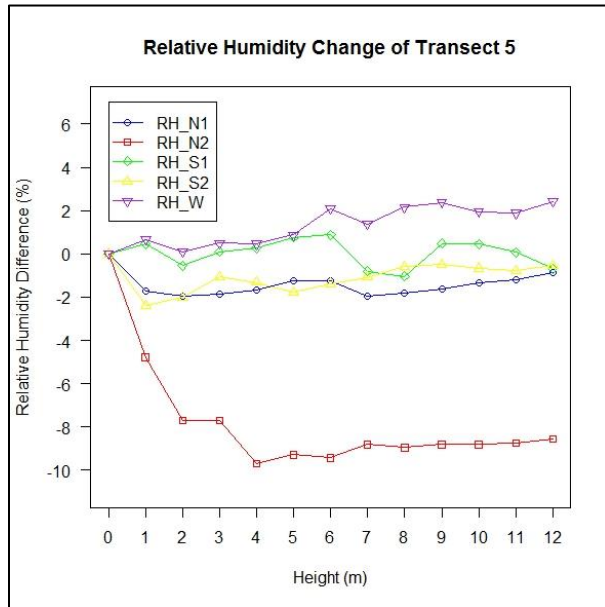
b)



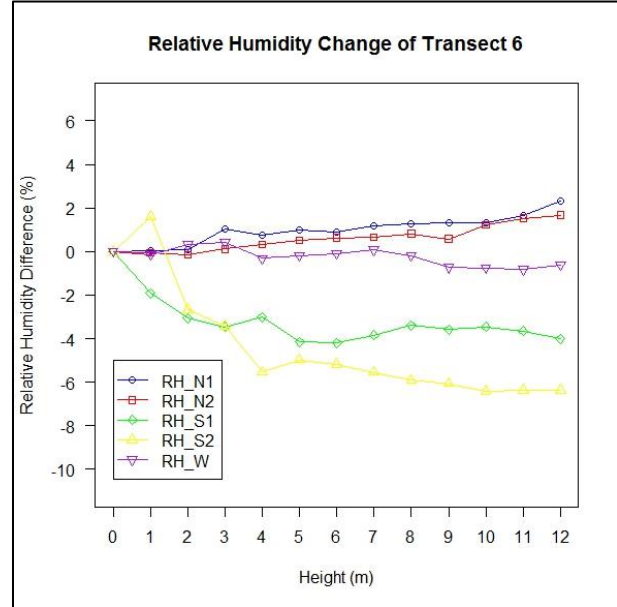
c)



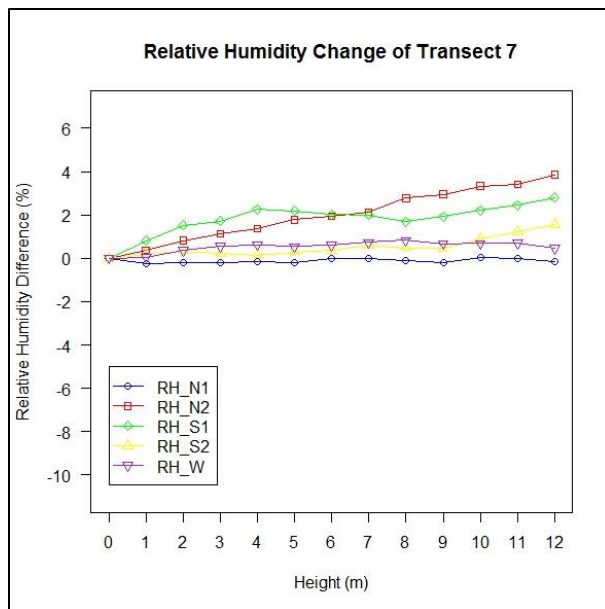
d)



e)



f)



g)

Figure 28 Relative Humidity Changes of Transects 1-7

According to these one-time field measurements and line graph plotting, there is no recognizable spatial pattern of changes of relative humidity in the study area. The relative humidity increases in some sites as the altitude increasing and decreases in other sites. The sites that relative humidity increases are more than those that relative humidity decreases. No strong evidence in

“RH\_W” represents the site above the center of the creek; “RH\_N1” represents the site which is the nearer one from the north bank of the creek; “RH\_N2” represents the farther site from the north bank; “RH\_S1” represents the site which is the nearer one from the south bank of the creek; “RH\_S2” represents the farther site from the south bank. Relative humidity difference means the difference between the RH of the specific height and the RH of 0m (surface).

Relative humidity data were collected: a) from 10:10 am to 10:30 am on August 1<sup>st</sup>, 2016; b) from 11:20 am to 11:50 am on August 1<sup>st</sup>, 2016; c) from 1:30 pm to 2:10 pm on August 1<sup>st</sup>, 2016; d) from 2:50 pm to 3:15 pm on August 1<sup>st</sup>, 2016; e) from 11:00 am to 11:25 am on August 2<sup>nd</sup>, 2016; f) from 12:50 pm to 1:20 pm on August 2<sup>nd</sup>, 2016; g) from 1:45 pm to 2:20 pm on August 2<sup>nd</sup>, 2016.

The location of the water center site of each transect is: a) 43.084167 N, 78.734167 W; b) 43.070121 N, 78.76892 W; c) 43.06488 N, 78.80387 W; d) 43.038506 N, 78.82682 W; e) 43.026948 N, 78.831549 W; f) 43.023158 N, 78.866547 W; g) 43.021711 N, 78.879701 W.

this research to prove that there are differences of vertical relative humidity changes between the urban areas and the rural areas.

### 4.3.3 Effect of LULC

Different LULC types result in the different temperature and relative humidity distribution above the surface. The averages of temperature and humidity of the sites in the same LULC types were calculated and plotted in R (Figures 29 and 30).

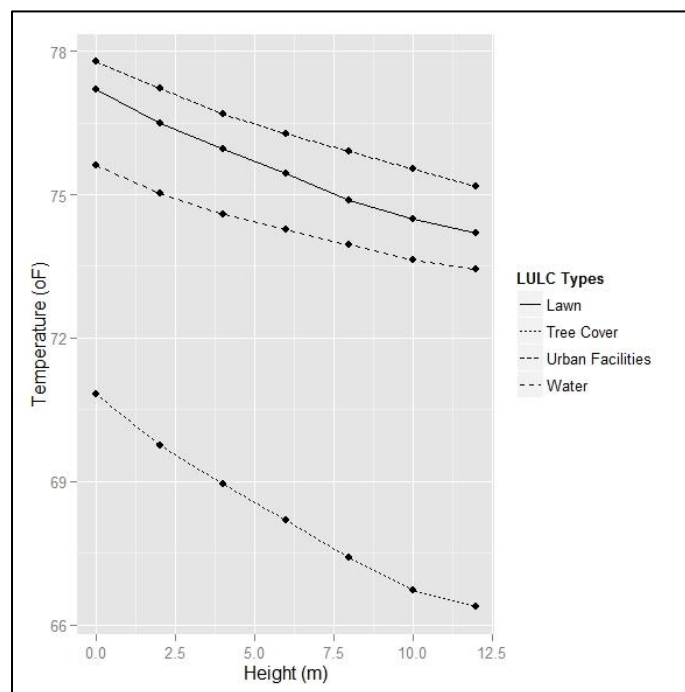


Figure 29 Temperature Changes Based on Different LULC Types

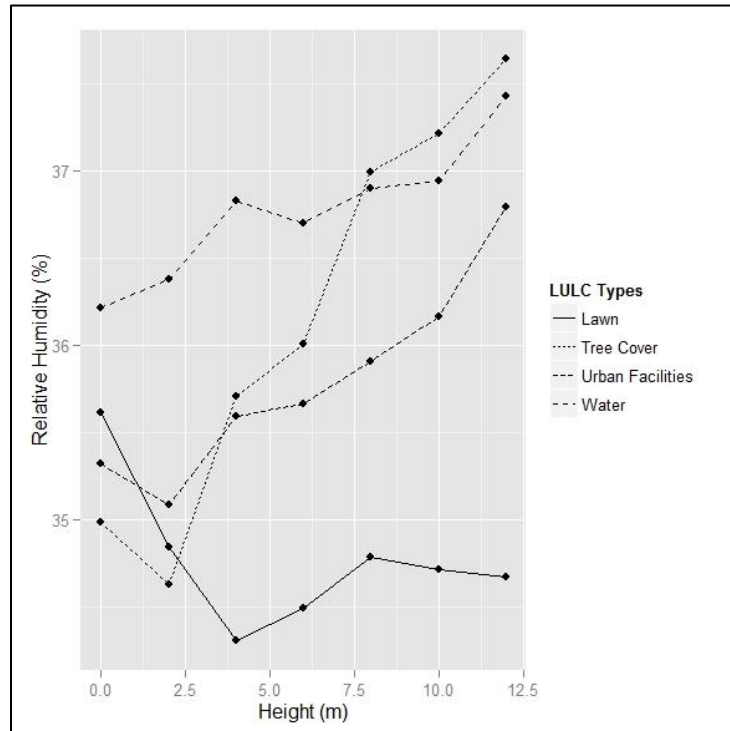


Figure 30 Relative Humidity Changes Based on Different LULC Types

Figure 29 shows obvious differences among the four LULC types. The air above urban facilities has the highest temperature, and the air above tree cover has the lowest. Figure 30 shows that tree cover underlying has the strongest positive effect on relative humidity as height increasing, and lawn underlying has negative effect on relative humidity as height increasing. Generally, the air above water has higher relative humidity. Since there were much more urban facility sites and lawn sites than tree cover sites, there could be some errors in the results.

According to the results of this research, LULC types have strong impacts on the growth of water chestnut, since this species prefers the environment with intensive and frequent human activities. In the meantime, LULC have strong impact on temperature and relative humidity as well. In summary, the highest concentration and re-appearance of water chestnut invasive species are either at the public park areas with large lawn or grassland cover or at the boat docking sites

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in the urban areas. However, there is no obvious evidence to explain the effect of habitat conditions of temperature and relative humidity (RH) on the growth of water chestnut.

## **5. Conclusions**

### **5.1 The Factors Influencing Water Chestnut Growth**

#### **5.1.1 Land Use and Land Cover**

The lower Tonawanda Creek is located in the north part of Tonawanda area in the Erie County. The Town of Tonawanda, the urban part of the study area, is covered by a large percent of lawn. However, the lawn areas are divided into small pieces by the roads, the buildings and other human made urban utilities. In the rural area of the study region, the land is covered by large patches of lawn or grassland, farmland, and forest.

According to the data of field survey from 2010 to 2016, the two island parks along the lower Tonawanda Creek are two areas that grow more water chestnut than other sites in the study area, which are the Ellicott Island Park and the Amherst Veterans Canal Park. The two island parks are at the two sides of the Niagara Falls Blvd respectively. The Niagara Falls Blvd is one of the main roads with heavy traffic. The docking sites of ships and boats also provide good conditions for water chestnut to grow. According to the previous studies of the growing conditions of the water chestnut, the areas having heavy human and animal activities are the best region for the species to grow.

As is mentioned by Hummel et al. (2004) and Countryman (1978), water chestnut is most abundant in sheltered bodies of water; Winne (1950) also said swiftly flowing water is detrimental to the survival of water chestnut. In the lower Tonawanda Creek, the docking sites



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provide relatively stable shelters for water chestnut. Winne (1950) and Kiviat (1993) mentioned that water chestnut likes nutrient-rich habitat. We can suspect that the areas having more human and animal activities may have more nutrients, because human and animals can let out something with nutrients, especially nitrogen, into water, such as food, pets' feces, etc.

### **5.1.2 Habitat Conditions**

The environmental conditions can be affected by the different LULC types. In small areas with micro-climatic conditions, LULC has influences on the spatial distribution of temperature and relative humidity. In the study area, the water surface of the creek is the mainly land cover type influencing temperature and relative humidity. The farther distance from the centerline of the creek, the higher the temperature and the lower the relative humidity. The large patches of lawn also impact the distributions of temperature and relative humidity a lot. The farther distance from the lawn, the lower the temperature and the higher the relative humidity. The three dimensional distribution pattern of temperature also shows the effect of different LULC types. As the altitude increasing, the temperature decreases slowly in the rural area and decreases rapidly in the urban area. However, the LULC does not have clear influence on the three dimensional distribution pattern of relative humidity in micro climatic scale environment according to the field surveyed data in this research. There is also no relationship between habitat conditions of temperature and relative humidity (RH) and the distribution of water chestnut plants.

Muenschler (1944), Countryman (1937) and Hummel et al. (2004) all indicated water chestnut likes to grow in the polluted water. The nutrient concentration is much more important than the habitat condition of temperature and humidity for water chestnut to grow.

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In conclusion, this research suggests that LULC types have effect on the growth of water chestnut, that water chestnut species grows more in the areas having more human activities, which are public parks and boat docking sites in the urban areas along the creek. LULC types also have impacts on environmental conditions (temperature and relative humidity). Among the land cover types, waterbodies can modify the temperature and relative humidity most, lawns take the second place. The modifying pattern is to decrease the temperature and increase the relative humidity. Although LULC types have impact on the growth of water chestnut and the environmental conditions in the study area, the results of this research suggest that there is no relationship between the growth of water chestnut and the environmental habitat conditions of temperature and relative humidity (RH).

## **5.2 Assessments of Current Management**

The current method of water chestnut management in the Tonawanda Creek is the physical removal of the plants before the maturation of the seeds. According to the field surveying data of water chestnut during 2010 to 2016 along the lower Tonawanda Creek, the physical removal method is very effective in controlling the water chestnut invasive species. The field survey data shows fact that the plant occurrences in 2015 were more than that in 2014. This proves that the seeds of water chestnut have a 10-12 year period of dormancy. Therefore, although no large number of water chestnut plants was discovered during field survey of 2016, the researchers and biologists at the Lower Great Lakes Fish and Wildlife Conservation Office should continue the removing work for several years in the near future to guarantee that all the water chestnut individuals in the lower Tonawanda Creek are fully removed.

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### 5.3 The Future Research of Applying UAV to Detect Invasive Species

Recently, the UAV technology has been developed rapidly. In comparison to the traditional satellite based or airborne imagery remote sensing platforms, the UAVs have advantages of lighter weight and lower cost, and can be deployed at any location and time the researchers prefer (Laliberte et al., 2010; Honkavaara et al., 2013). It will become more and more popular, especially in the large scale and small area oriented studies. The high resolution cameras carried on the unmanned helicopters or UAVs make it possible to detect the individuals or small patches of invasive species, which cannot be recognized by satellites or regular airborne remote sensing. However, several limitations exist in particular for the UAVs we used in this study: 1) although the batteries of Phantom 3 have improved and can last longer than those of Phantom 2 models, they still can only last no more than 25 min flying time per battery; 2) owing to the light weight, the UAVs or unmanned helicopters can be blown away easily by wind; 3) most of current models of UAVs are not water proof, which are not safe enough to fly in the rain or detect aquatic species on the water surface, such as water chestnut in this study; 4) when controlling the UAV, we should keep the drone in sight, otherwise, it may be crashed onto trees or power lines.

In the future, the UAV industry should develop with long lasting batteries, and more stable aircrafts that are able to fly in bad weather conditions, such as strong wind and heavy rainfall.

Although some waterproof UAVs have already been manufactured in the US, the image sensor or photographic technology of these types were not well developed, which means these products cannot take very high resolution images as the DJI products do. The future UAVs may combine the two technologies together and create the amphibious system. Hopefully, the UAVs can fly along the pre-programmed routes and avoid barriers automatically and intelligently.

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## 6. Bibliography

- ArcGIS*. Computer software. Vers. 10.4.1. N.p., n.d.
- Besha, J.A., & Countryman, W.D. (1980). *Feasibility assessment of anaerobic digestion of European water chestnuts (Trapa natans L.)*. New York State Energy Research and Development Authority 80-13, Albany.
- Bickley, W.E., & Cory, E.N. (1955). *Water caltrop in the Chesapeake Bay*. Assoc. of Southeastern Biol. Bull. 2:27-28.
- Bove, A. & Hunt, T. (1997). *Water chestnut: An exotic plant invasion in Lake Champlain*. In Proceedings of the Second Northeast Conf. on Nonindigenous Aquatic Nuisance Species. 18-19.
- Brunsdon, C., Fotheringham, A.S. & Charlton, M. (2007). *Geographically weighted discriminant analysis*. Geographical Analysis. 39, 376-396.
- Carlson, T.N., & Ripley, D.A. (1997). *On the relation between NDVI, fractional vegetation cover, and leaf area index*. Remote Sensing of Environ. 62:241-252.
- Chaovalit, P., & Zhou, L. (2005). *Movie review mining: A comparison between supervised and unsupervised classification approaches*. In Proceedings of the 38th annual Hawaii international conference on system sciences (pp. 112c-112c). IEEE.
- Chen, J., Jönsson, P., Tamura, M., et al. (2004). *A simple method for reconstructing a high-quality NDVI time-series data set based on the Savitzky–Golay filter*. Remote sensing of Environ, 91(3): 332-344.
- Childs, C. (2004). *Interpolating surfaces in ArcGIS spatial analyst*. ArcUser, July-September, 3235.
- Colditz, R.R., Schmidt, M., Conrad, C., et al. (2011). *Land cover classification with coarse spatial resolution data to derive continuous and discrete maps for complex regions*. Remote Sensing of Environ, 115: 3264-3275.
- Comber, A.J. (2008). *"Land use or land cover?"* J. of Land Use Sci. 3: 199-201.
- Countryman, W.D. (1978). *Nuisance aquatic plants in Lake Champlain*. Vermont: New England River Basins Commission v, 102p.(Lake Champlain Basin Study technical reports no. 23)-Illus., Prepared for the Eutrophication Task Force. Geog, 3.
- Cronk, J.K. & Fennessy, M.S. (2001). *Wetland plants: Biology and ecology*. Lewis Publishers, Boca Raton, FL.
- Del Barrio, G., Alvera, B., Puigdefabregas, J., & Diez, C. (1997). *Response of high mountain landscape to topographic variables: Central Pyrenees*. Landscape Ecol. 12: 95-115.
- Department of Environment Conservation. (2010). *Niagara River/Lake Erie WI/PWL- Lower Tonawanda Creek Watershed*.

- 
- Ding, J., Blossey, B., Du, Y., & Zheng, F. (2006). *Galerucella birmanica* (Coleoptera: Chrysomelidae), a promising potential biological control agent of water chestnut, *Trapa natans*. *Biol. Control*. 36: 80–90.
- Elser, H.J. (1964). *Control of water chestnut by machine, in Maryland, 1964-65*. *Proc. Northeastern Weed Conf.* 20:682-687.
- Flora of China. (2007). Vol. 13: 290-291.
- Forman, R.T. (1990). *Ecologically sustainable landscapes: the role of spatial configuration*. In *Changing landscapes: an ecological perspective*. Springer New York. 261-278.
- Fotheringham, A.S., Brunson, C., & Charlton, M.E. (2002). *Geographically weighted regression: The analysis of spatially varying relationships*. Chichester, UK: Wiley.
- Goovaerts, P. (2000). *Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall*. *J. of Hydrol.* 228(1): 113-129.
- Greeley, J.R. (1960). *A new 2,4-D amine pellet for eradication of water chestnut*. *Proc. Northeast. Weed Control Conf.* 14:488-495.
- Gwathmey, J.H. (1945). *Potomac River cleared of 'floating island'*. *Md. Conservation*. 21:1-3.
- Hall, R.E. (1982). *The effects of leaf and stem damage on fruit production in the water chestnut (Trapa natans)*. M.S. thesis, Union College, Schenectady, NY.
- Havel, J.E., Kovalenko, K.E., Thomaz, S.M., et al. (2015). *Aquatic invasive species: challenges for the future*. *Hydrobiol.* 750:147-170.
- Honkavaara, E., Saari, H., Kaivosoja, J., et al. (2013). *Processing and assessment of spectrometric, stereoscopic imagery collected using a lightweight UAV spectral camera for precision agriculture*. *Remote Sensing*, 5:5006-5039.
- Hoque, A., Davey, M.R. & Arima, S. (2009). *Water chestnut: potential of biotechnology for crop improvement*. *J. of New Seeds*. 10:180-195.
- Hummel, M. & Kiviat, E. (2004). *Review of World Literature on Water Chestnut with Implications for Management in North America*. *J. Aquat. Plant Manage.* 42: 17-28.
- Hunt, T. & Marangelo, P. (2012). *2011 Water Chestnut Management Program: Lake Champlain and Inland Vermont Waters, Final Report*. Vermont Department of Environ.Conserv.
- Hutchinson M.F. 1995. Interpolating mean rainfall using thin plate smoothing splines. *Int. J. of Geogr. Inf. Syst.* 9: 385–403.
- Jansen, L.J., and Di Gregorio, A. (2002). *Parametric land cover and land-use classifications as tools for environmental change detection*. *Agric., ecosyst., & environ.* 91: 89-100.
- Jeffrey, S.J., Carter, J.O., Moodie, K.B., & Beswick, A.R. (2001). *Using spatial interpolation to construct a comprehensive archive of Australian climate data*. *Environ. Modelling & Software*, 16(4): 309-330.

- 
- Jensen, J.R. & Jensen, R.R. (2013). *Introductory Geographic Information Systems*. Pearson Series.
- Joshi, C., de Leeuw, J., & van Duren, I.C. (2004). *Remote sensing and GIS applications for mapping and spatial modelling of invasive species*. In Proceedings of ISPRS Vol. 35, p. B7.
- Krupauer, V. (1971). *The use of herbivorous fishes for ameliorative purposes in central and eastern Europe*. Proc. European Weed Res. Council Int. Symp. on Aquat. Weeds. 3:95-101.
- Kiviat, E. (1993). *Under the spreading water-chestnut*. News From Hudsonia. 9:1-6.
- Laliberte, A.S., Herrick, J.E., Rango, A., & Winters, C. (2010). *Acquisition, orthorectification, and object-based classification of unmanned aerial vehicle (UAV) imagery for rangeland monitoring*. Photogrammetric Engineering & Remote Sensing, 76: 661-672.
- Madsen, J.D. 1993. Waterchestnut seed production and management in Watervliet Reservoir, New York. J. Aquat. Plant Manage. 31:271-272.
- Maki, K., & Galatowitsch, S. (2004). *Movement of invasive aquatic plants in Minnesota (USA) through horticultural trade*. Biol. Conservation. 118:389-396.
- Manandhar, R., Odeh, I.O., & Ancev, T. (2009). *Improving the accuracy of land use and land cover classification of Landsat data using post-classification enhancement*. Remote Sensing, 1(3): 330-344.
- Masocha, M. and Skidmore, A.K. (2011). *Integrating conventional classifiers with a GIS expert system to increase the accuracy of invasive species mapping*. Int. J. of Applied Earth Observation and Geoinf. 13:487-494.
- Michael, N., Mellinger, D., Lindsey, Q., & Kumar, V. (2010). *The grasp multiple micro-UAV testbed*. IEEE Robotics & Automation Magazine, 17:56-65.
- Mills, E.L., Leach, J.H., Carlton, J.T., & Secor, C.L. (1993). *Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions*. J. of Great Lakes Res, 19(1): 1-54.
- Mitas, L., & Mitasova, H. (1999). *Spatial interpolation*. Geogr. Inf. Syst: principles, techniques, management and applica. 1: 481-492.
- Moore, I.D., Turner, A.K., Wilson, J.P., et al. (1993). *GIS and land surface-subsurface process modelling*. In: Goodchild, M.F., Parks, B., Steyaert, L.T. (Eds.), Environmental Modeling with GIS. Oxford Univ. Press, Oxford, pp. 196-230.
- Muenschler, W.C. (1937). *Water chestnut*. In: A biological survey of the lower Hudson watershed. New York Conservation Department, Supplement to 24<sup>th</sup> Annual Report (1935), Albany. 234-243, 246.
- Muenschler, W.C. (1944). *Aquatic plants of the United States*. Cornell University Press, Ithaca, NY.
- Naylor, M. (2003). *Water Chestnut (Trapa natans) in the Chesapeake Bay Watershed: A Regional Management Plan*. Maryland Department of Natural Resources.

- 
- Ninyerola, M., Pons, X. & Roure, J.M. (2000). *A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques*. Int. J. of Climatol. 20: 1823-1841.
- NYIS. (2014). *New York invasive species clearinghouse: species profile - banner graphic of water chestnut*.
- Rahel, F.J., Bierwagen, B., & Taniguchi, Y. (2008). *Managing aquatic species of conservation concern in the face of climate change and invasive species*. Conservation Biol. 22: 551-561.
- Rahel, F.J., & Olden, J.D. (2008). *Assessing the effects of climate change on aquatic invasive species*. Conservation Biol. 22:521-533.
- Rector, P.R., Nitzsche, P.J., & Mangiafico, S.S. (2015). *Temperature and herbicide impacts on germination of water chestnut seeds*. J. of Aquat. Plant Manage. 53:105-112.
- Rundquist, B. (2010). *Unsupervised classification*
- Saadat, H., Adamowski, J., Bonnell, R., et al. (2011). *Land use and land cover classification over a large area in Iran based on single date analysis of satellite imagery*. ISPRS J. of Photogrammetry and Remote Sensing, 66: 608-619.
- Tiner, R.W. (2000). *Wetlands of Saratoga County, New York: Vital resources for people and wildlife*. Cooperative National Wetlands Inventory Publication, U.S. Environ. Protection Agency, New York.
- Tonawanda Creek Watershed*. Prepared by Tonawanda Creek Watershed Committee. Download from the linkage: [http://www.wcsxcd.org/images/uploads/Tonawanda\\_Creek\\_Brochure.pdf](http://www.wcsxcd.org/images/uploads/Tonawanda_Creek_Brochure.pdf)
- Veldkamp, A., & Verburg, P.H. (2004). *Modelling Land Use Change and Environmental Impact*. J. of Environ. Manage. 72:1-4.
- Winne, W.T. (1950). *Water chestnut: A foreign menace*. Bull. to the Schools 36:230-234.
- Zhu, F. (2016). *Chemical composition, health effects, and uses of water caltrop*. Trends in Food Sci. & Technol. 49:136-145.