Water Balance in the Holland Marsh
Final Report


(Geovisuals , 2014)

Globomatics Inc.

Project ID: 201415-07

6/17/2015

June 17, 2015
Project ID: 201415-07

Mr. Brett Ruck
Executive Director
Drainage Investment Group
4321 Queen Street
Niagara Falls, Ontario
L2E 2K9

Dear Mr. Ruck

RE: Final Report – Water Balance in the Holland Marsh

Please accept this letter as formal submission of Project 201415-07: Water Balance in the Holland Marsh for the Drainage Investment Group, completed by Globomatics Incorporated.

The goal of this project was to calculate the water balance of the Holland Marsh, and identify the areas with excess or deficit of water. The project provides an understanding of climatic trends and spatially determines where the Marsh requires improved land management practices.

The findings found that the Holland Marsh is trending to becoming a more moderate micro climate, with increasing winter average temperatures, decreasing summer average temperatures. These temperatures are accompanied by an annual decrease in precipitation volumes, with more regular extreme events occurring (two 10-year events within the past 10 years).

If you have any questions or concerns about the details contained in this document, please feel free to contact us at josh8valenti@gmail.com, or by phone at (905) 515-2666.

Regards,

Josh Valenti
BSc (Hons.) Physical Geography
GIS-GM Graduate Certificate Candidate
JV/

Enclosures: Water Balance in the Holland Marsh – Final Report
Cc: Ryan Roque – GIS Analyst, Ian Smith – Project Advisor

Executive Summary

Globomatics Inc. is a newly founded consulting organization created in association with Niagara College in September 2014. Globomatics Inc. strives to provide the best quality geospatial solutions for Southern Ontario in both the private and public sectors. Their technical and management skills in conjunction with GIS, and the professional expertise of project advisor Ian Smith, has provided the Drainage Investment Group (DIG) with a unique business opportunity.

This document comprises of the third and final deliverable for the Water Balance in the Holland Marsh project. This final report highlights the results of the analysis done during the timeframe of October 2014 to June 2015. Consisting of project background, goals and objectives, literature review, methodology, findings, challenges, recommendations, and conclusions, this report summarizes the final outcome. Project management aspects are also included with the project schedule and budget in place.

Each phase of the project was completed successfully, with limited setbacks. The key outcomes of this final stage are as followed:

- Interpolated climatic data:
    - Winter temperatures increasing, summer temperatures decreasing, causing a more moderate microclimate. Precipitation events decreasing in annual volumes, with more regular extreme events.
    - Moderate increase in water balance from 2005-2014, with an average 289,376.25m^3 of inputted water per year.
- Final project cost of $34,000.00 is under the proposed budget of $42,600.00 calculated on March 2015 as a part of the project proposal,

As the Holland Marsh contains such valuable land and rely on the climate to produce the best products available, Globomatics Incorporated recommends to install a climatic monitoring station and stream monitors within the marsh. Stations within the marsh will offer the best benefits to analyzing and predicting future climatic patterns to help maintain the successful business plan.

Through investigation of the Holland Marsh, this study can be contributed to a much larger-scale project: preservation of the agricultural land. Globomatics, in collaboration with the Drainage Investment Group and Niagara College, has provided an analysis for the benefit of any future river restoration and management initiatives. This water balance project had been completed successfully as of June 2015.

Table of Contents

List of Tables

List of Figures

List of Equations

1 Introduction

1.1 Project Background

The Holland Marsh is a remarkably unique area in terms of farmland and agricultural activity. The Marsh is referred to as the "Salad Bowl of Ontario" because of its fertile soil and ability to grow a wide variety of fresh produce. Located in Bradford, Ontario, Canada, the Holland Marsh is one of only two designated Specialty Crop Areas in Ontario, alongside the Tender Grape and Fruit Area located within the Niagara Region (The Friends of the Greenbelt Foundation, 2015). Covering an area of 2900 hectares, the Holland Marsh is home to approximately 250 farms managed by 100 farmers. The Marsh produces a large concentration of vegetables contributing to 95% of Ontario's celery, 66% of Ontario's onions, 80% of Ontario's carrots, and 90% of Ontario's Asian greens (Walton and Hunter Planning Associates, 1999). Annually, the Marsh produces over one billion dollars in revenue, making it some of the most productive soils in Canada (Ontario Ministry of Agriculture, Food and Rural Affairs, 2013).

1.2 Project Understanding

The Marsh was drained in the early 1920's strictly for agricultural use. This process consisted of the construction of canals that travel along the north and the south borders of the marsh, allowing for the Holland River to flow at controlled rates through the heart of the marsh and drain north into Cook's Bay of Lake Simcoe. Over the last decade, the Holland Marsh has experienced drainage issues, causing valuable land to flood and as a result, the destruction of crops. Along with flooding, soil erosion has become a primary concern, as the water flow has become a key factor in depleting the land available for agricultural production (Planscape Inc. , 2009).

To mitigate against events destructive to the land, a water balance has been calculated for the past decade (2004 to 2014). This analysis investigated the system by calculating the difference between the amount of incoming water (through precipitation) and the outgoing water (through evaporation). A surplus of water has been occurring in recent times within the Marsh, causing fields to be completely submerged under water. This occurs when the amount of incoming water (precipitation, inflows from surface, and groundwater) exceeds that of the storage capacity and the output (evapotranspiration, and output flows) of a system.

1.3 Study Area

Located in Bradford, Ontario, the Holland Marsh is located 50 kilometers north of Toronto. The ability to grow and harvest one billion dollars in produce each year, is a result of the incredibly fertile muck soil.

Figure 1-1 on the following page displays the location of the Holland Marsh.

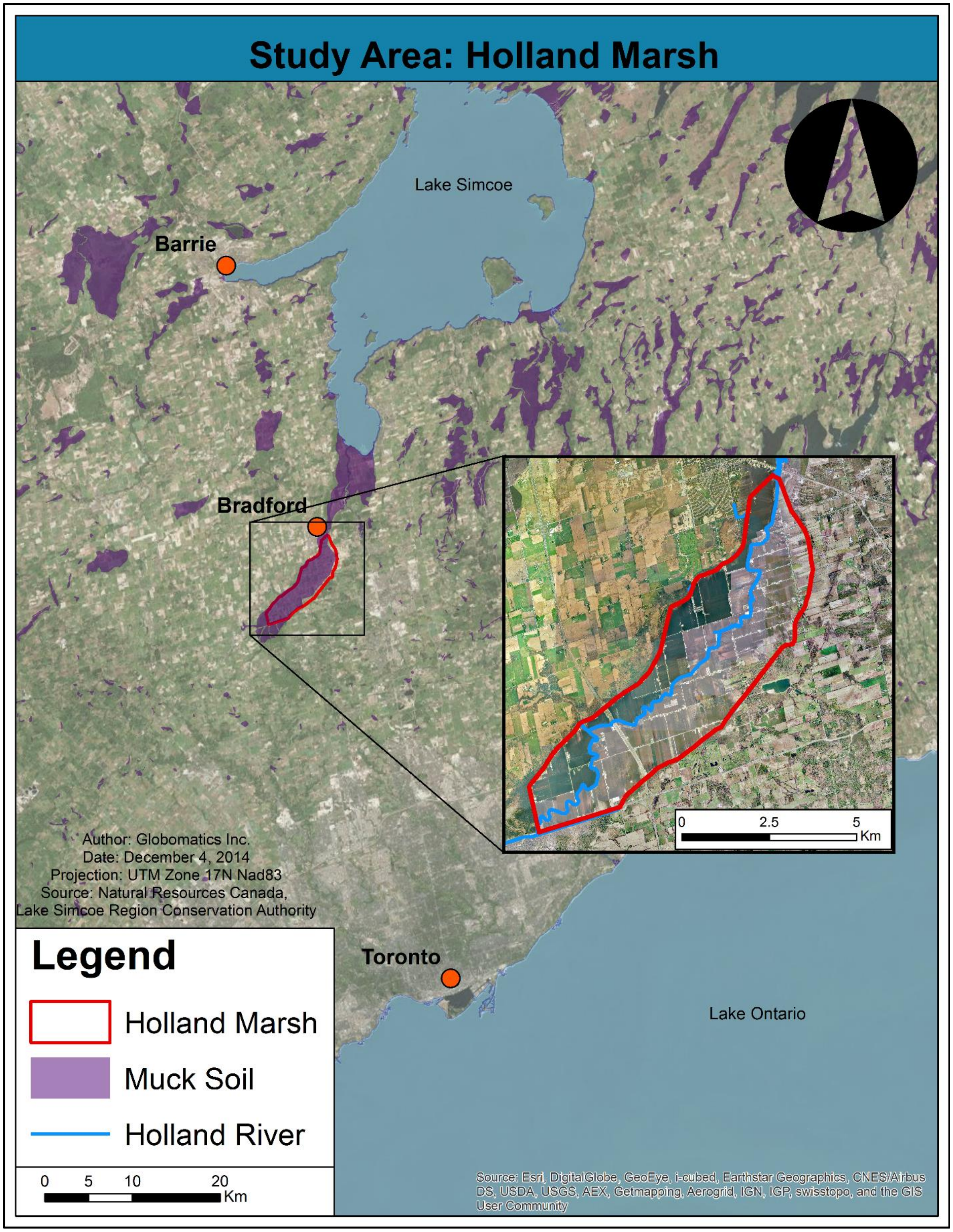


Figure 1-1: Study Area - Holland Marsh

2 Project Goal and Objectives

2.1 Project Goal

The project goal was to derive and calculate the water balance of the Holland Marsh to allow for the identification of areas which have a distinct surplus or deficit in water. By investigating past climatic trends, the water balance was calculated on a seasonal basis to highlight these distinct areas. The long-term goal of this analysis was to observe the impact the water balance has on the Marsh, and to contribute these results to the river restoration project.

2.2 Project Objectives

In order to calculate the water balance of the Holland Marsh, an analysis of climate data from the past decade was undertaken to identify trends in climatic variables (Temperature, Precipitation, Solar Radiation, etc.). In return, these data were processed to identify locations which have excess or deficit of water within the lower South-West region of the Marsh.

The objectives of this project are outlined as the follows:

- Obtain and manage meteorological data;
- Undertake an analysis of meteorological data from the previous decade, identifying trends in climatic variables;
- Produce climatic variable maps and graphics for seasonal periods;
- Calculate solar radiation maps for seasonal periods; and
- Calculate water balance of the Holland Marsh for seasonal periods over the last decade.

For a detailed description on how these objectives were completed, please refer to Section 4.

2.3 Project Deliverables

The goal and objectives stated above were initiated in October 2014, as a part of the project proposal process (Valenti & Rouque, Water Balance in the Holland Marsh: Project Proposal, 2015), with final completion anticipated for June 2015. Three main deliverables were planned, consisting of a presentation and report. These deliverables summarize the work done for each phase (Proposal, Progress, and Final).

The Proposal deliverables outlined the initial process of the Water Balance effort. The project team, background information and project goal, were established. Project resources, schedule, and budget were also estimated to maintain project integrity. This provided a timeline for both Globomatics Inc. to follow to manage time accordingly as well for the client, the Drainage Investment Group (DIG), to have an understanding of how the project was going to be completed (Valenti & Rouque, Water Balance in the Holland Marsh: Project Proposal, 2015).

The Progress deliverable provides a detailed methodology outlining the steps taken to complete the study. This primarily involved research of a water balance in the Marsh, as well as data collection requirements. A field trip was organized to gain in-situ information of the study area. A background literature review was completed to investigate past studies of climatic water balances, as well as studies done in the Marsh. Finally, data were collected, organized, and reviewed for the impending analysis to be done.

The Final deliverable highlights the concluding results of the water balance analysis. A report of each aspect of the complete project is exhibited through these deliverables.

The major project deliverables are outlined in Table 1, including completion dates and status.

Table 1: Summary of Project Deliverables

Phase	Deliverables	Presentation Date	Report Submission Date	Status
1	*Proposal Presentation & Report*	December 2, 2014	December 5, 2014	Complete
2	*Progress Presentation & Report*	March 20, 2015	March 25, 2015	Complete
3	*Final Presentation & Report*	June 10, 2015	June 17, 2015	Complete

3 Literature Review

An agricultural economic impact study conducted by Walton & Hunter Planning Associates provided information regarding the significance of Holland Marsh's contribution towards the fruit and vegetable industry in the Greater Toronto Area (GTA) (Walton and Hunter Planning Associates, 1999). A considerable amount of carrots, onions, and various greens are grown in the area. In addition to larger vegetable producers, it also gains a competitive advantage because of its proximity to the market. Despite the economic importance of the industry, rapid farmland loss is apparent. Concerns on the impact of excess nutrients, the use of pesticides, and soil erosion have been expressed. These issues are all potentially associated to the water flow from the Holland River, making analyses of the water resources relevant for the management of the land. To summarize this study, agriculture in the GTA area is a resource worth protecting due to the great economic value of the land. A more recent study by Planscape had similar observations (Planscape Inc. , 2009). Management of water was described as being complex, with various infrastructures which support agriculture.

Within the past decade, recent developments in GIS techniques have allowed for the wide range of powerful methods for capturing, displaying and understanding climatic data (Wypych, 2012). In 2012, Agnieszka Wypych used the GIS environments to calculate the Climatic Water Balance (CWB) of Poland to study the accuracy of a variety of GIS methods, exploring regression models, and Map Algebra. It was found that the Map Algebra produced the greatest results with Pearson's correlation of 0.988 while the next highest resultant was multiple regression with a Pearson's correlation of 0.950. This research provided Globomatics Inc. with the framework for the methodology outlined in Section 4 below. The results of

Annual water balances are done for Lake Simcoe, by the Lake Simcoe Region Conservation Authority (Lake Simcoe Region Conservation Authority, 2013). The report for 2007-2009 contains the efforts to identify and measure sources of phosphorus in the watershed, as well as accounting for quantitative hydrological data and lake water balances. Technical details of the methodology used for these components are provided. For the annual water balance, factors such as discharge from tributaries, urban point sources, and precipitations were described as the supply terms. In contrast, discharge from the Lake Simcoe outlet, evaporation, and storage, were considered loss terms. The water balance in the Lake Simcoe area for 2007-2009 was reported to be -3%. The Holland Marsh volume contributed to 1% of this annual hydrologic input.

To supplement the understanding of economic importance and water balance methods, ex-situ flow analyses were introduced by project advisor Ian Smith (Smith, 2015). The literature provided served as an introduction to Flood Recurrence (Flow Duration Analysis) and allowed for a preliminary analysis of precipitation events to be done.

3.1 Climatic Water Balance

Wypych provided a significant framework for the methods used to undertake a water balance investigation (Wypych, 2012). Validation of the study showed that map algebra was the best calculation method, which uses an equation based on precipitation totals (P) and potential evapotranspiration (PET) to calculate the Climatic Water Balance (CWB). Turc's formula was used to calculate the potential evapotranspiration values (Turc, 1961), using air temperatures and solar radiation as input variables. The formula was derived is as follows:

Equation 3-1: Climatic Water Balance

$$CWB = P - PET$$

$$PET = 0.4 \frac{t}{t + 15} I + 50$$

Where:

CWB = Climatic water balance [mm]

P = Monthly precipitation totals [mm]

t = Monthly average temperature [°C]

I = Monthly sum of total solar radiation [cal cm^{-2} day^{-1}]

3.1.1 Map Algebra

Map algebra was the most successful approach used in Wypych's study. As the first CWB component, Temperature spatial differentiation maps were created using the residual kriging method. As predictor variables for air temperature, three parameters were used; elevation, latitude, and longitude. Precipitation totals were interpolated using the ordinary kriging method. The solar radiation surface were obtained through the Solar Analyst tool in ArcGIS. The Solar Analyst tool used necessary information including sun hours, altitude for the study area, radiation parameters (diffuse and transmissivity), and topographical factors to calculate the solar radiation for the Holland marsh on monthly intervals. The process of this map algebra is shown in Figure 3-1: Workflow for Map Algebra.

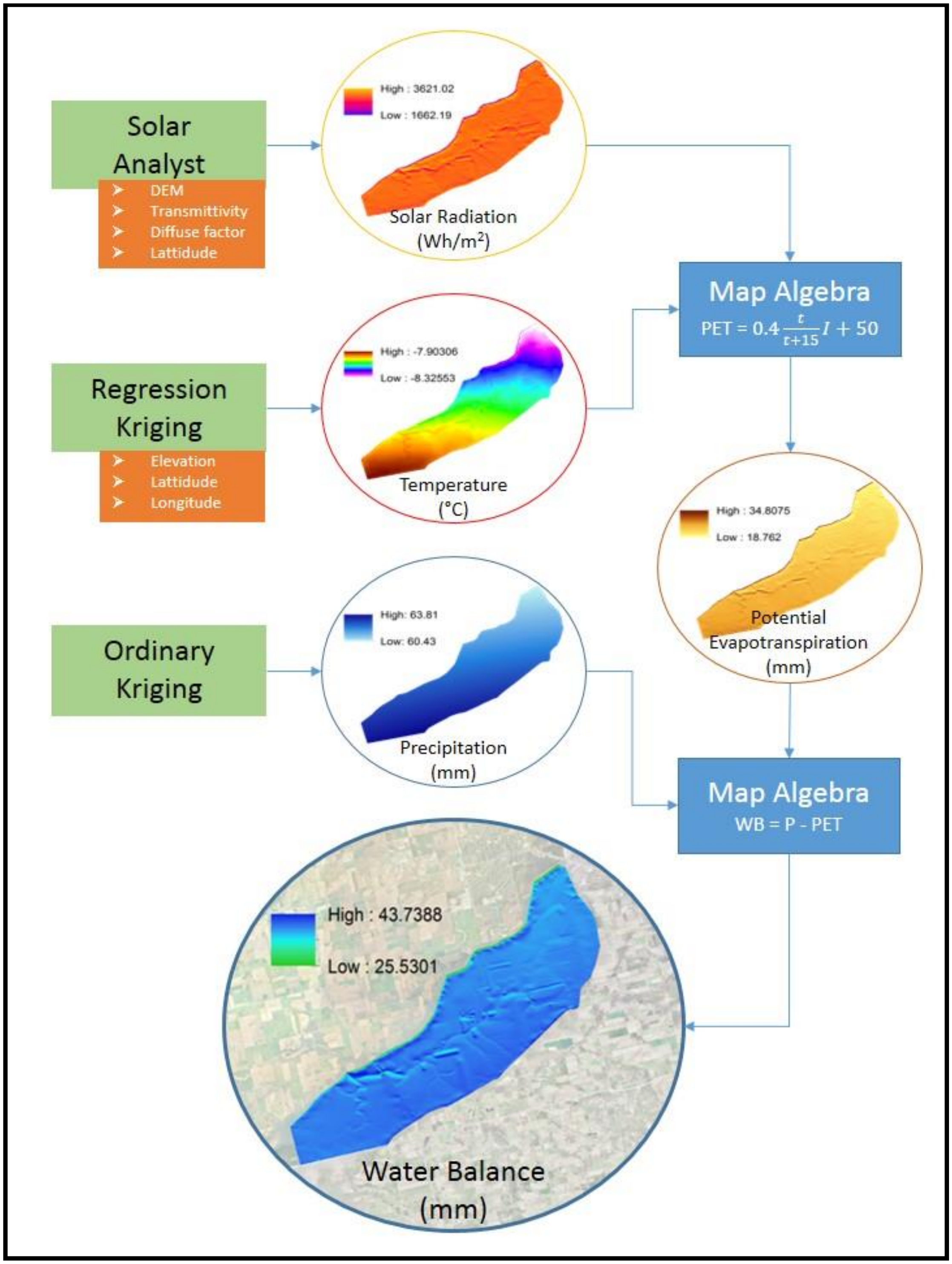


Figure 3-1: Workflow for Map Algebra

4 Methodology

In accordance to project management practices, a Work Breakdown Structure (WBS) was created which divides each stage of the project into specific tasks. The WBS is shown below in Figure 4-1.

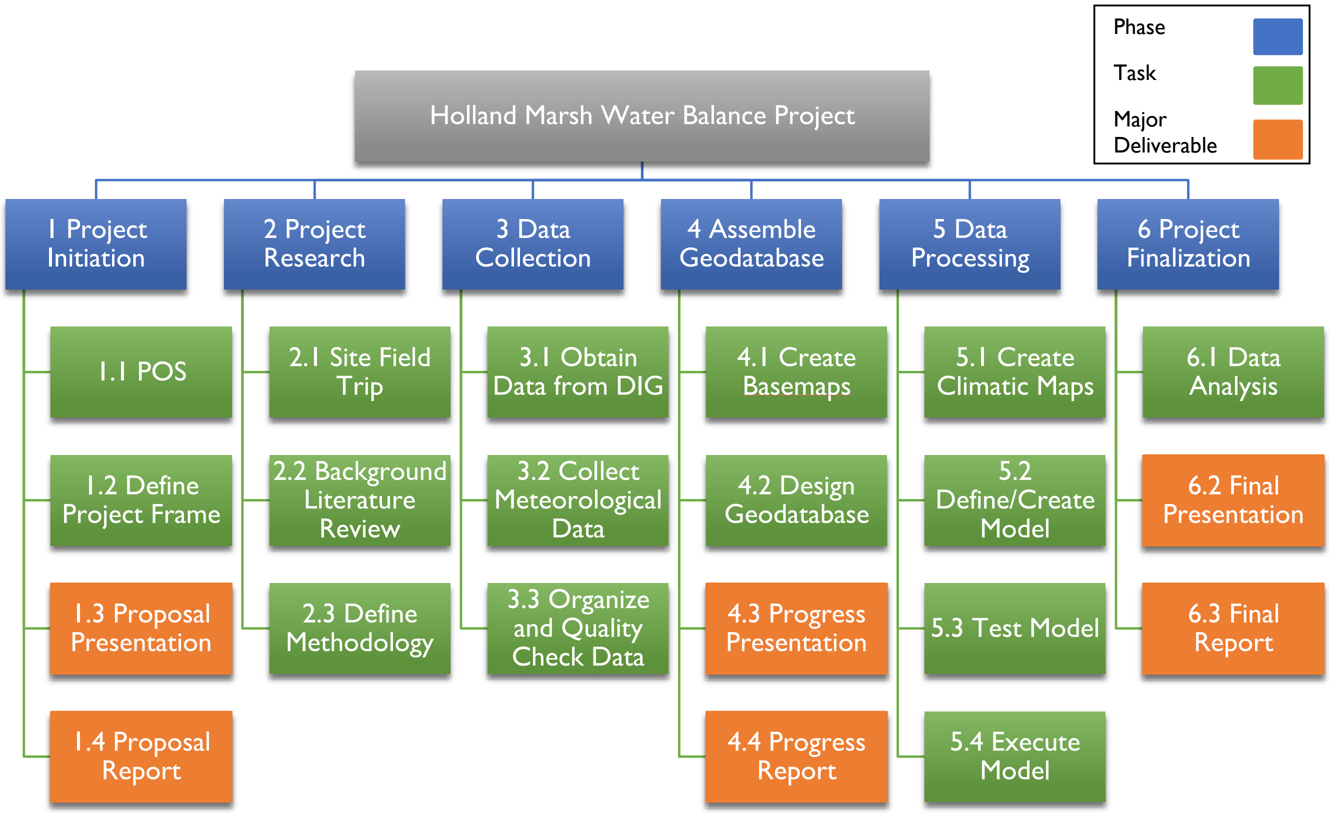


Figure 4-1: Work Breakdown Structure

4.1 Project Initiation

The first phase consisted of preparing and planning of the project. Familiarization with the project goal, objectives and deliverables are critical in this stage. With a thorough assessment of the original terms of reference (Appendix A), a Project Objective Statement (POS) is constructed to clearly outline the specific details of the project. This includes elements such as the business problem, objectives, benefits, deliverables, conditions, success factors, and timeframe estimates. The approved POS can be found in Appendix B.

After approval of the POS, additional time was spent detailing the specifics of the schedule. This was done to ensure that each stage of the project goes as planned. By preparing a well-defined schedule, this can limit any issues and constraints regarding the timeframe. In addition to the schedule, a project budget was estimated for the proposed tasks and resources.

To conclude project initiation, a proposal presentation and report were completed in December 2014. The proposal presentation consisted of a spoken summary of the planning process. This included an introduction of the project team, goals, deliverables and management. The Proposal Report went into much more depth about the projected details of the project. Overall, these deliverables were able to improve our own comprehension of the project planning aspect, as well as the client's.

4.2 Project Research

The second phase consisted of obtaining knowledge needed to begin the study. A field trip to the Holland Marsh gave us firsthand look at the study area. Through a tour of the Marsh, information was gained regarding the existing problems. Furthermore, the significance of the agricultural land was noted, emphasizing the importance of the project.

As stated earlier, a background literature review is done to gain a complete understanding of the study site, water balance methods, and other supplementary information. The details of the literature review can be found in Section 3.

4.3 Data Collection

Data collection for this project consisted of data provided by the client (DIG), as well as data obtained by Globomatics Inc. through Environment Canada and the University of Toronto. The three required datasets needed were temperature, precipitation, and solar radiation. Environment Canada has multiple weather stations throughout Ontario, however there are zero located within the Holland Marsh. Due to lack of stations within the marsh, weather stations located within 50 km were used to statistically calculate and interpolate for the necessary climatic variables.

Four primary stations were selected based on the criteria that they contained daily temperature and precipitation values on a consistent basis. These stations were located in Richmond Hill, Orangeville, Baldwin, and Egbert. Following a quality check of the data sources, it was found that there was some discrepancies within the data (missing values). To account for these discrepancies, a nearby secondary station was selected for each primary station to compensate and supply the missing data. The secondary stations include Alliston, Udora, Toronto/Buttonville, and the Sandhill Station. Below in Figure 4-2, is a map visualizing the locations of the primary and secondary weather stations.

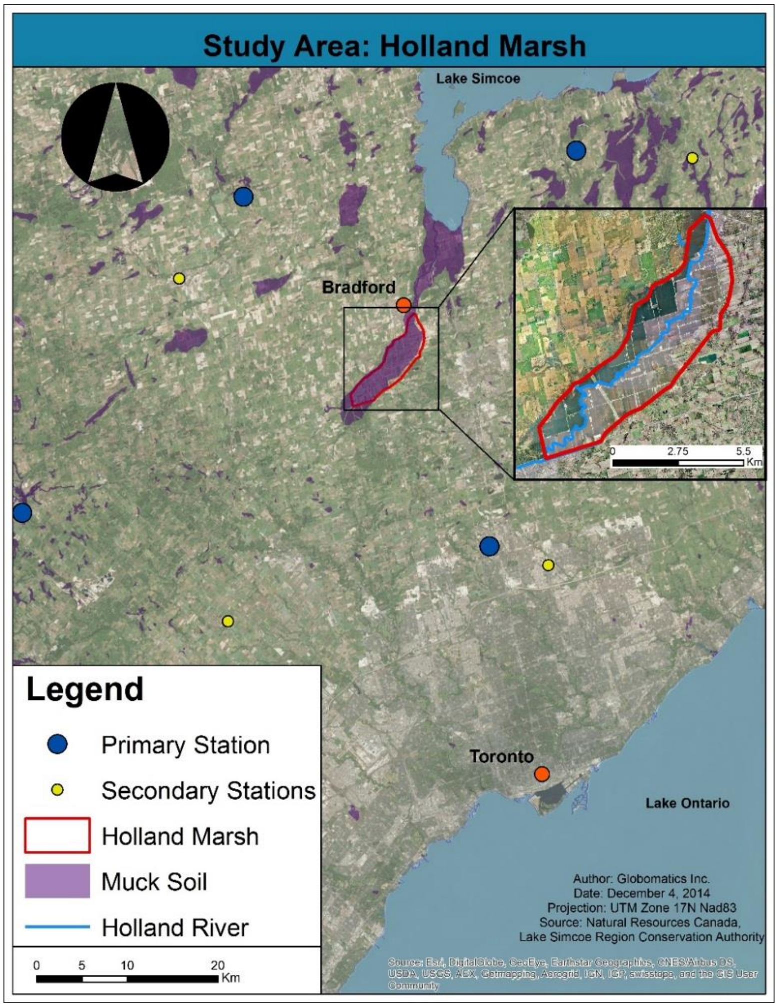


Figure 4-2: Data Collection Stations

The solar radiation dataset were obtained through the University of Toronto from 2008 to 2012. The reason for the missing data (2004-2007, 2013-2014) is to maintain data integrity. The station has replaced the sensors during 2007 and 2012. Averages calculated from 2008-2012 years were used to as the values during the years with missing data to keep the source consistent. The datasets which were acquired are summarized in Table 1, along with the collection details and sources.

Table 2: Data Sources

Data Set	Collection Details	Source
Baldwin Station[1]	2004-2014 (Daily)	Environment Canada (2015a)
Egbert CS Station[1]	2004-2014 (Daily)	Environment Canada (2015b)
Orangeville MOE Station[1]	2004-2014 (Daily)	Environment Canada (2015c)
Richmond Hill Station[1]*	1964-2013 (Daily)	Environment Canada (2015d)
Alliston Station[2]	2007 (Daily)	Environment Canada (2015e)
Sandhill Station[2]	2014 (Daily)	Environment Canada (2015e)
Toronto Buttonville Station[2]	2014 (Daily)	Environment Canada (2015e)
Udora Station[2]	2014 (Daily)	Environment Canada (2015e)
Solar Radiation	2008-2012	University of Toronto (2012)
DEM (10m)	Tile #091d_w_m	Ontario Ministry of Natural Resources (2006)
DEM (4cm)	Southwest location	Lake Simcoe Region (2014)
Orthoimagery (4cm)	Southwest location	Lake Simcoe Region (2014)
Orthoimagery (20cm)	2007	Ontario Ministry of Natural Resources (2007)
*Station used to calculate precipitation events, [1]Primary Station, [2]Secondary Station.		

4.4 Geodatabase Assembly

This stage consisted of creating a geodatabase to contain the collected data. This allowed the data to be easily accessible, and organized, making it more efficient for the future stages.

The daily climatic data obtained from Environment Canada and the University of Toronto were first organized and compiled into a Microsoft Access database, allowing for easy manipulation of daily data, and transforming it into monthly averages and sums. This data was then imported into a geodatabase within ArcGIS for further processing.

4.5 Data Processing

The data processing stage consisted of implementing the methodology outlined in the previous progress report. This was carried out through a set of models generated in ArcGIS's Model Builder (ESRI, 2015).

The first steps of the processing included statistical interpolation of the climatic variables. Interpolation involves the prediction of values at unmeasured locations (ESRI, 2013). The following interpolation of each variable was done using the methods derived from Wypych (Wypych, 2012):

- Temperature: interpolated by Residual Kriging,
- Solar radiation: interpolated by ArcGIS's Solar Analyst (ESRI, 2015),
- Precipitation: interpolated by Ordinary Kriging, and

- Water Balance: calculated using Map Algebra.

4.5.1 Map Algebra

Map Algebra is a way to perform spatial analysis in an algebraic language (ESRI, 2013). This tool allows for easy manipulation between datasets and variables. Map Algebra is unique in that it performs calculations on a cell-by-cell basis. The process is completed by creating a grid across the study area of a specific spatial resolution. This grid is then interpolated where a unique value is calculated for each cell. This can be seen below in Figure 4-3 and Figure 4-4.

Figure 4-4: Map Algebra, Example of how a raster creates a grid across the study area.

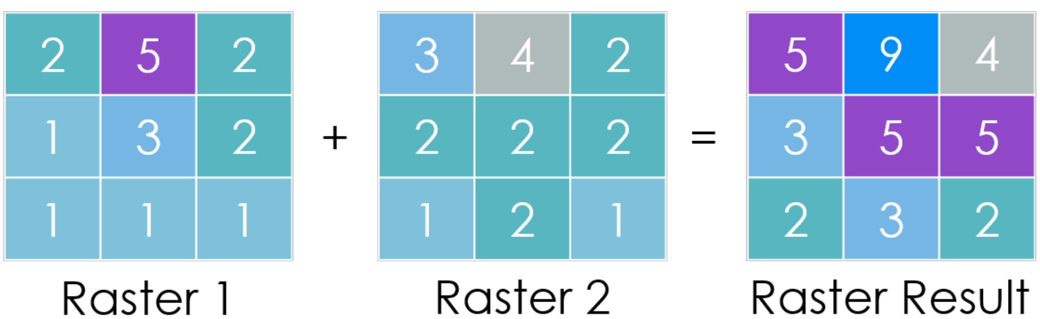


Figure 4-3: Example of how map algebra calculates on a cell be cell basis

4.5.2 Regression Kriging

Regression kriging was the method implemented for the temperature data. Three variables that have a major impact on a locations temperature are the longitude, latitude, and elevation. These variables were incorporated into the regression equation shown below as Equation 4-1.

Equation 4-1: Temperature Residual

$$Temperature = B_{Lat}R_{Lat} + B_{Long}R_{Long} + B_{Elev}R_{Elev} + B_{Int}$$

Where:

B_{Lat} = *Latitude*

R_{Lat} = *Latitude Residual*

B_{Long} = *Longitude*

R_{Long} = *Longitude Residual*

B_{Elev} = *Elevation (m.a.s.l)*

R_{Elev} = *Elevation Residual*

B_{Int} = *Model Intercept*

The temperature residuals were calculated on a monthly basis for the years 2004-2014 and spatially interpolated for the Holland Marsh. An example of the temperature interpolation for April 2005 is displayed in Figure 4-5.

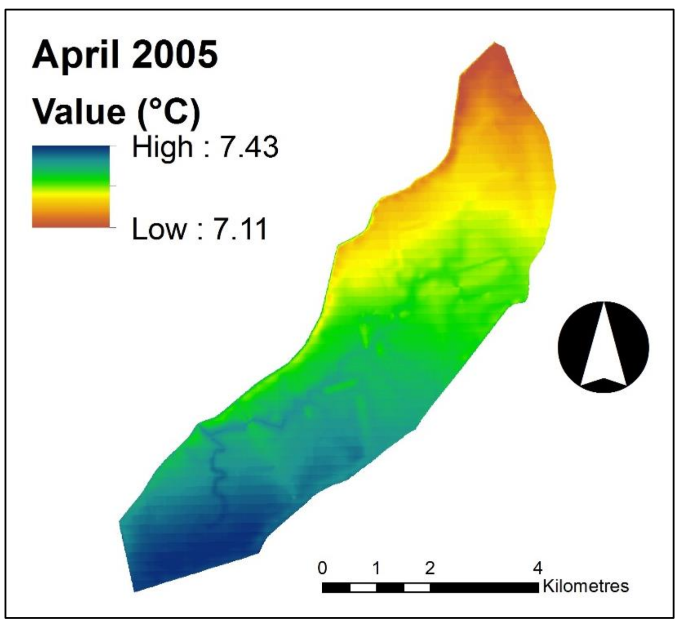


Figure 4-5: Temperature Surface Interpolation Example

4.5.3 Solar Analyst

ArcGIS's Solar Analyst tool was the application used for the calculation of the solar radiation surface. The recorded values obtained from the University of Toronto (UofT) were used as reference value to calculate the values for the Holland Marsh. The UofT station is located approximately 50 km south of the Holland Marsh. To account for the distance, a set of steps using ArcGIS's Solar Analyst tool were taken to produce the final interpolation result. An example of the solar radiation interpolation can be seen below in Figure 4-6 for April of 2005.

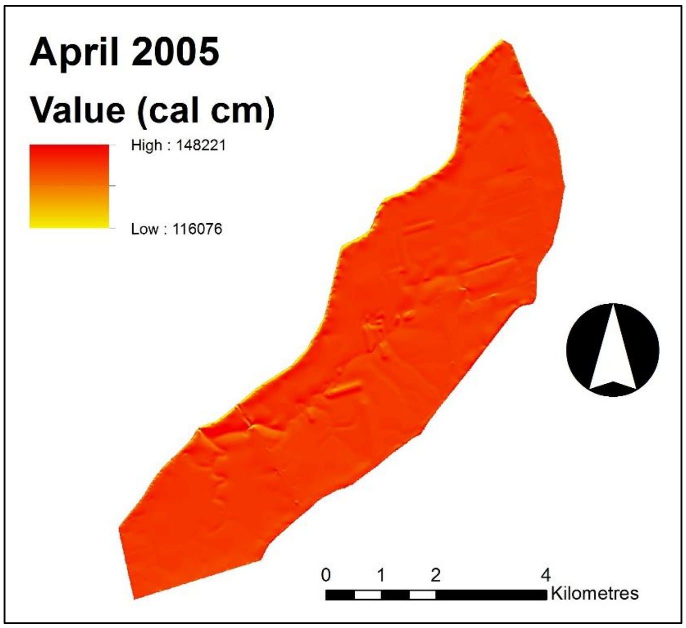


Figure 4-6: Solar Radiation Surface Interpolation Example

4.5.4 Ordinary Kriging - Precipitation

Daily precipitation data provided by Environment Canada was used with Ordinary Kriging for interpolation of the precipitation data surface. An example of the surface created for April of 2005 is visualized in Figure 4-7.

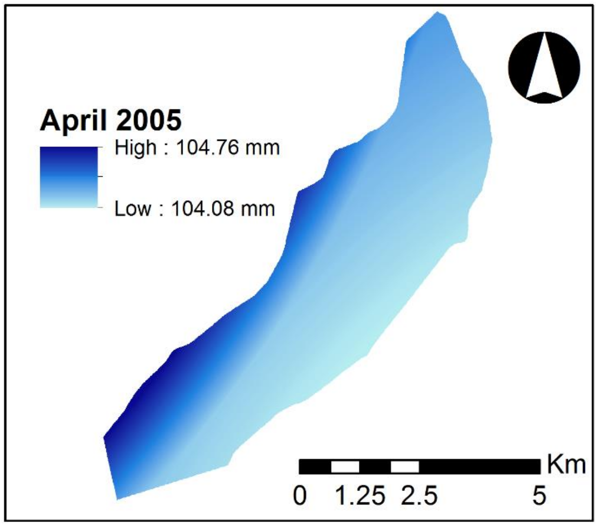


Figure 4-7: Precipitation Surface Interpolation Example

4.5.5 Map Algebra – Water Balance

The water balance was than calculated with the use of map algebra with each surface described above as the input variables for the water balance equation. This resulted in a water balance raster output, which is shown below in Figure 4-8.

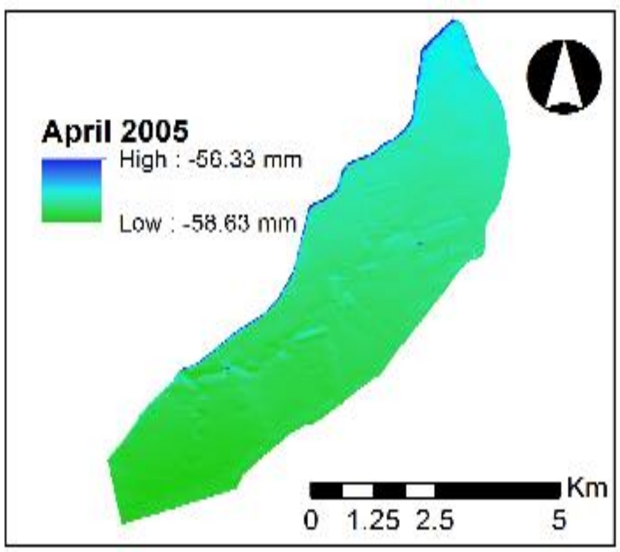


Figure 4-8: Water Balance Result Example

4.6 Project Finalization

After execution of the model, statistical analyses were undertaken to observe areas that have a deficit or excess in water and when throughout the year. Following the completion of these tasks, a final presentation was done on June 10, exhibiting the findings of the project, along with this final project report. The findings of this project can be found in Section 5.

4.7 Assumptions

Due to the nature of the project (scope and constraints) the following assumptions have been made:

- There is no change in soil moisture storage. The Holland Marsh is made up of only Muck soil and therefore any change in soil moisture storage will give rise to minimal change and can be disregarded.
- It is assumed the data collected from outside sources is correct following a Globomatics Inc. data quality check.
- It is assumed that the interpolated variables accurately represent data within the Holland Marsh.

5 Findings

This section evaluates the results achieved regarding the Water Balance in the Holland Marsh using the methodology described above in Section 4.

5.1 Climatic Variable Analysis

5.1.1 Temperature

Shown below in Figure 5-1 is the average monthly temperature for the interpolated surface of the Holland Marsh.

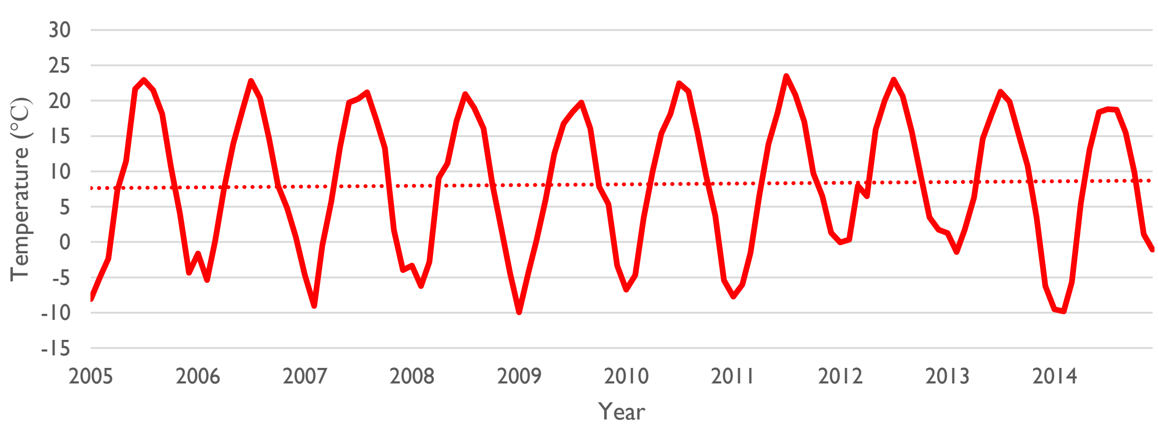


Figure 5-1: Average Monthly Temperature

Throughout the years there is a slight linear increase in the trend from approximately 7.50°C to 9.00°C. This trend is a result of higher minimum temperatures along with lower maximum temperatures across the year creating a more moderate annual temperature increasing by approximately 0.003°C per year. Table 3 below summarizes the annual are the yearly averages for the interpolated temperature.

Table 3: Yearly Average Temperature

Year	Average Temperature (°C)
2005	8.15
2006	8.71
2007	7.88
2008	7.22
2009	7.10
2010	8.53
2011	8.55
2012	10.40
2013	8.74
2014	6.24
Decade	8.08

As presented in the table, a high of 10.40°C occurred in 2012, while a low of 6.24°C took place in 2014. An overall average temperature for the decade is 8.08°C. Refer to Appendix C: for monthly data.

5.1.2 Solar Radiation

The average monthly solar radiation is displayed in Figure 5-2.

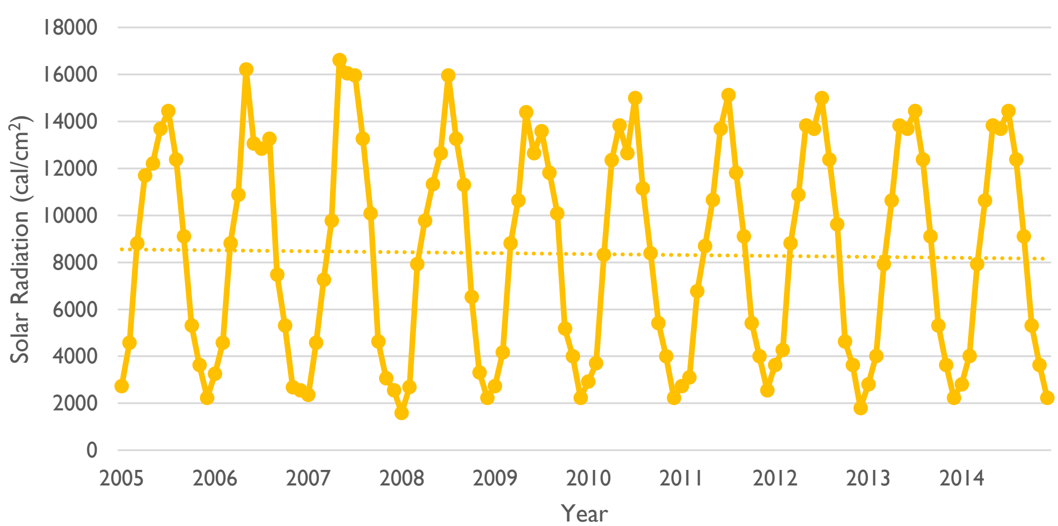


Figure 5-2: Average Monthly Solar Radiation

Over the past decade, the solar radiation within the Holland Marsh shows a trend decreasing over time. In the past 10 years the annual solar radiation trend has been decreasing by 24.78 cal/cm^2.

Table 4 Yearly Average Solar Radiation

Year	Average Solar Radiation (cal/cm^2)
2005	8405.99
2006	8413.47
2007	8853.39
2008	8215.32
2009	8361.47
2010	8333.29
2011	7809.72
2012	8516.24
2013	8336.89
2014	8336.89
Decade	8504.86

As presented in the Table 5-2, a high of solar radiation occurred in 2012 also corresponding to the highest temperature year. An overall average incoming solar radiation for the decade is 8504.86 cal/cm^2. Refer to Appendix B: for monthly data.

5.1.3 Precipitation

The average monthly precipitation of the interpolated area is shown below in Figure 5-3.

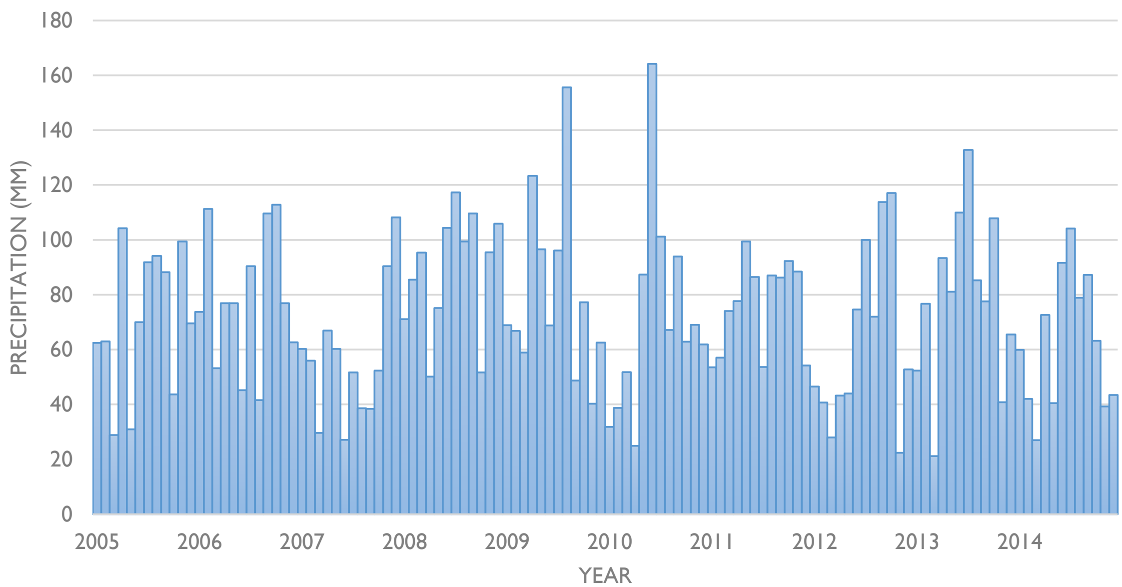


Figure 5-3: Average Monthly Precipitation

The highest monthly average is shown in June 2010 (164 mm). It is also observed that more precipitation occurs during the fall and summer months. The yearly averages are displayed below in Table 5.

Table 5: Yearly Average Precipitation

Year	Average Precipitation (mm)
2004	63
2005	70
2006	78
2007	57
2008	88
2009	80
2010	71
2011	76
2012	63
2013	79
2014	62
Decade Average	72

As presented in the table, a high of 88 mm occurred in 2008, while a low of 57 mm took place in 2007. The overall average precipitation for the decade is 72 mm. See Appendix A: for monthly data.

5.1.4 Water Balance

The summarized water balance results for the past decade are shown below in Figure 5-4.

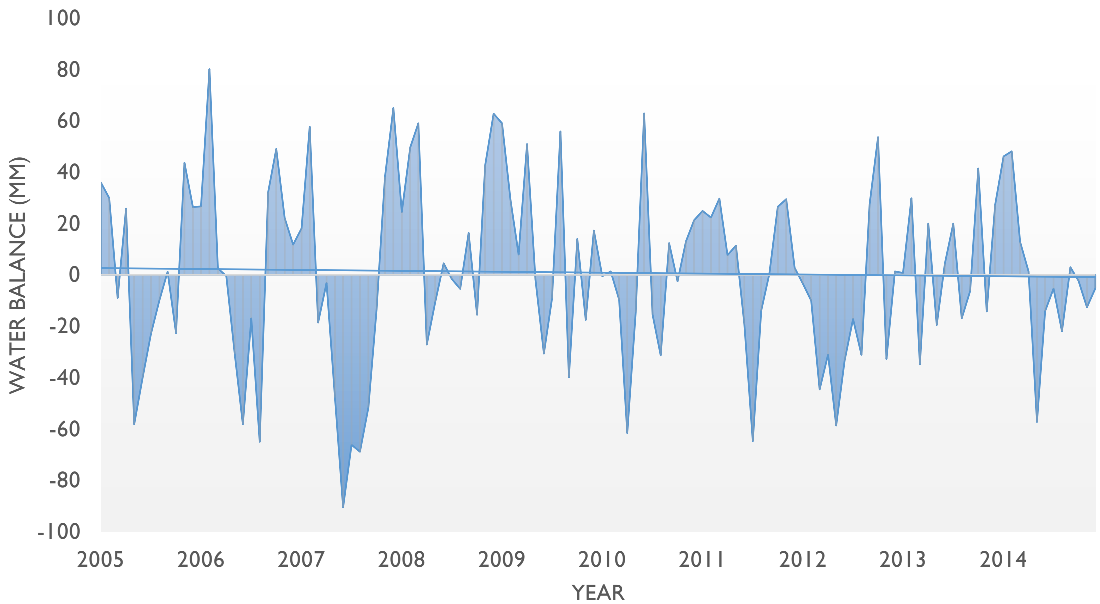


Figure 5-4: Water Balance by Month

The average of the monthly water balance is calculated to be -1 mm with a standard deviation of 35. These water balance surfaces are observed seasonally in the following sections. The yearly water balance is also shown below in Table 6. Refer to Appendix D: for monthly water balance results.

Table 6: Yearly Average Water Balance

Year	Average Water Balance (mm)
2005	0
2006	53
2007	-182
2008	199
2009	135
2010	-25
2011	57
2012	-181
2013	52
2014	-8
Decade Average	0.847127

5.2 Seasonal Analysis

Seasonal analysis of the climatic variables are shown below.

5.2.1 Winter

Summarized below is the water balance results for the winter season from 2005-2014 (Figure 5-5)

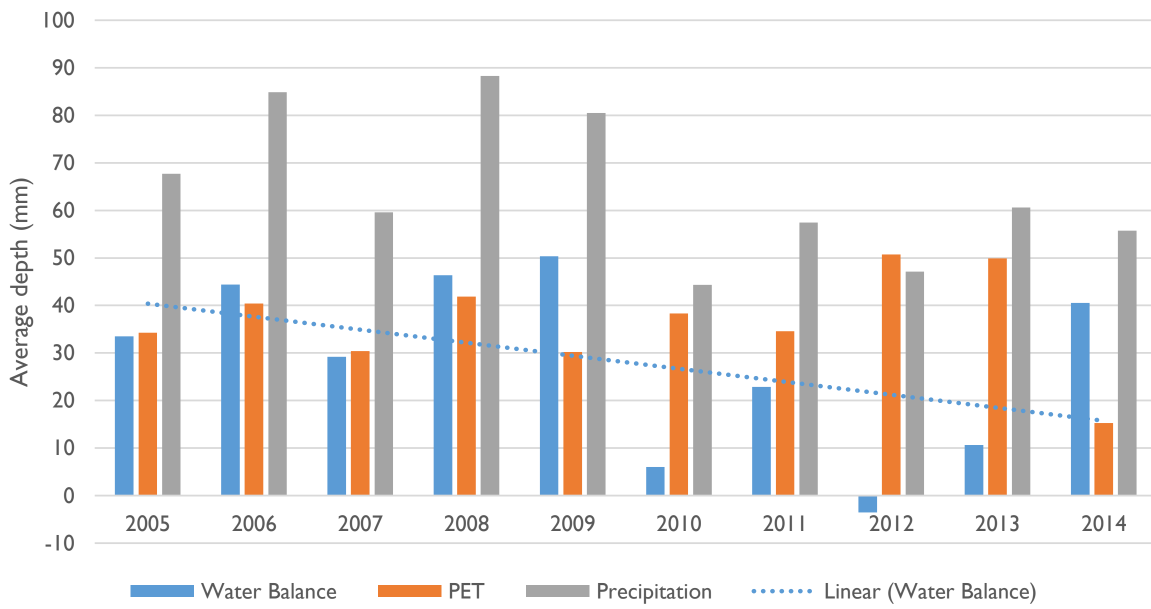


Figure 5-5: Winter Water Balance Summary

As depicted in the graph, every year has produced a positive water balance (with the exception of 2012). This means that precipitation is the more dominant variable, contributing more input than output to the system. Overall, the average water balance for the winter in the past decade is calculated to be approximately 28mm with a standard deviation of18.5mm. The minimum average winter water balance in 2012 was calculated to be -3.58mm with a high of 50.32mm during winter of 2009. The results for the winter are visualized spatially in Figure 5-6 and Figure 5-7 the following pages.

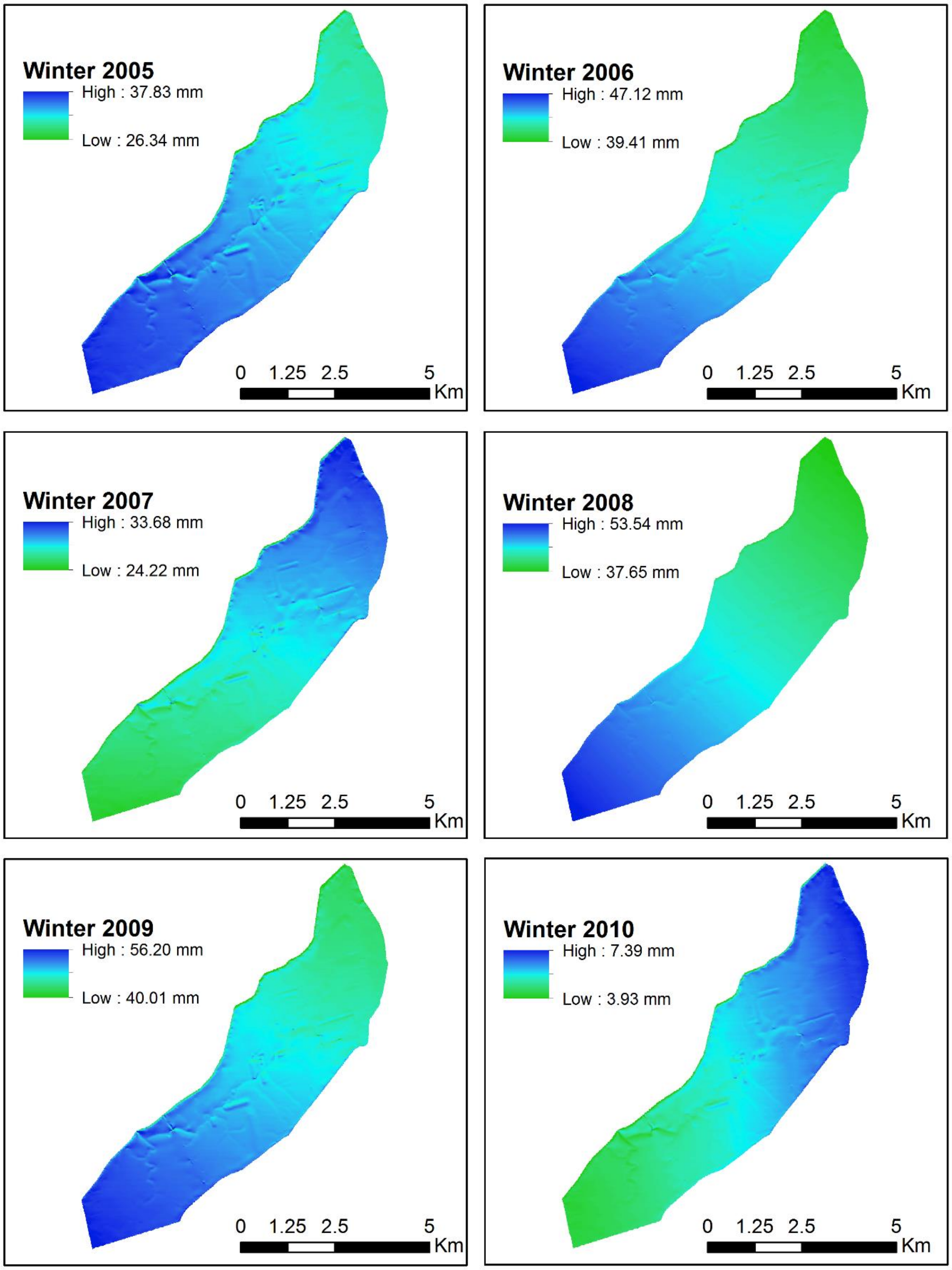


Figure 5-6: Winter Water Balance (2005-2010)

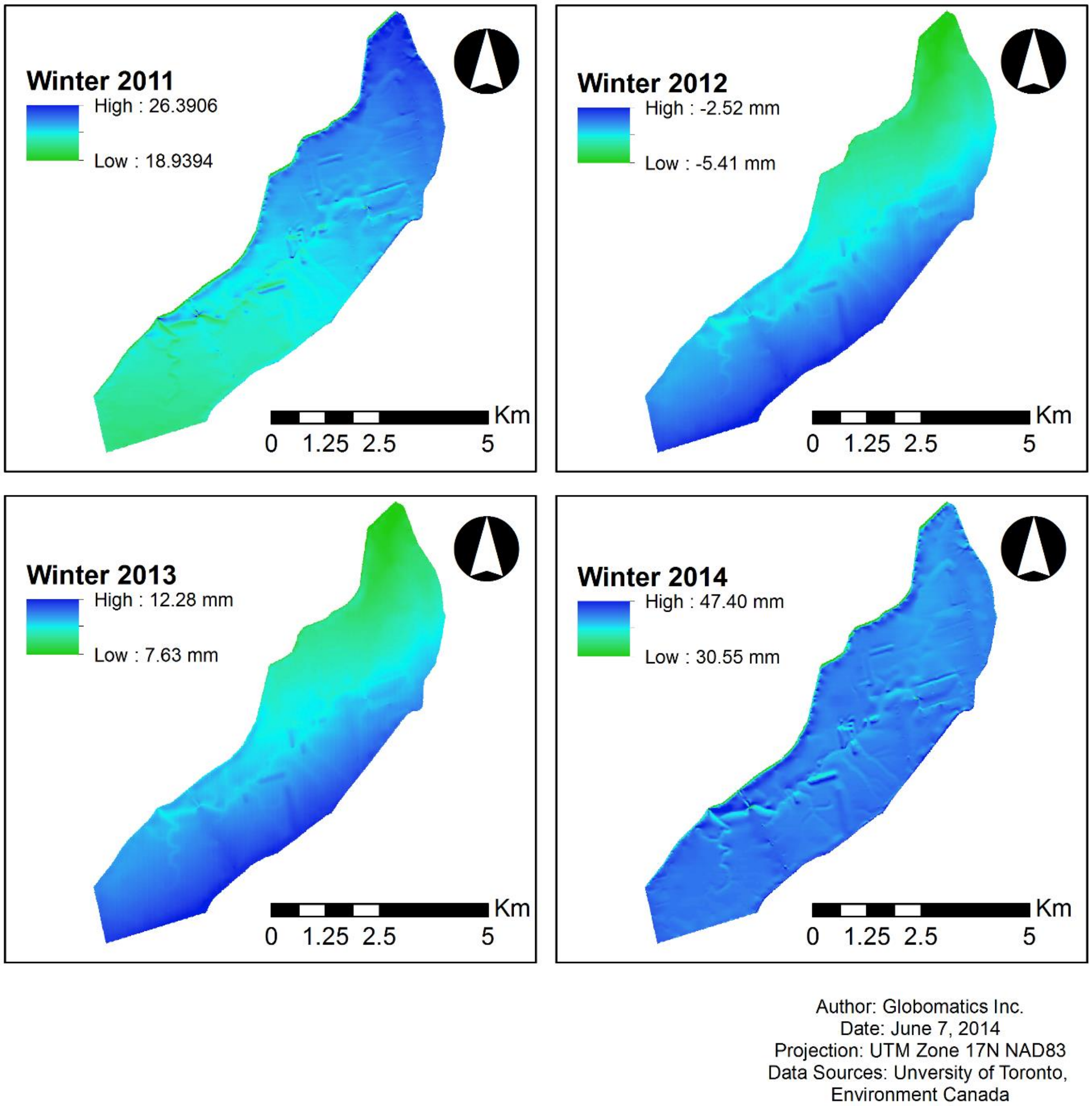


Figure 5-7: Winter Water Balance (2011-2014)

5.2.2 Spring

Summarized below is the water balance results for the spring season (Figure 5-8).

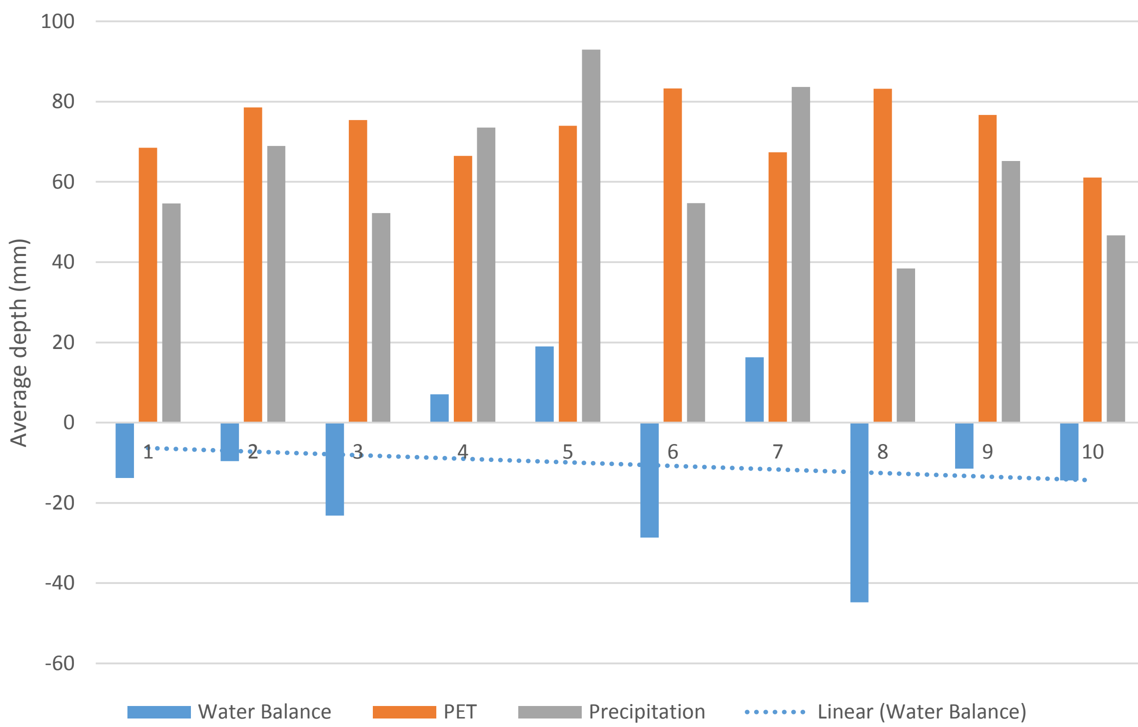


Figure 5-8: Spring Water Balance Summary

As depicted in the graph, the majority of the years have a deficit in average water balance (with the exception of 2008, 2009, and 2011). This means that evapotranspiration is the more dominant variable during the spring months, resulting in a greater output than input of water into the system. Overall, the average water balance for the spring in the past decade is calculated to be approximately -10.36mm with a standard deviation of 19.97mm. The minimum average water balance can is found during 2012 (consistent with the winter minimum) with a minimum average of 10.36mm, and a high during 2009 with a maximum average of 18.99mm. The trend seems to be decreasing over the previous decade, with the output becoming substantially greater. The results for the spring are depicted spatially in Figure 5-9 and Figure 5-10 on the following pages.

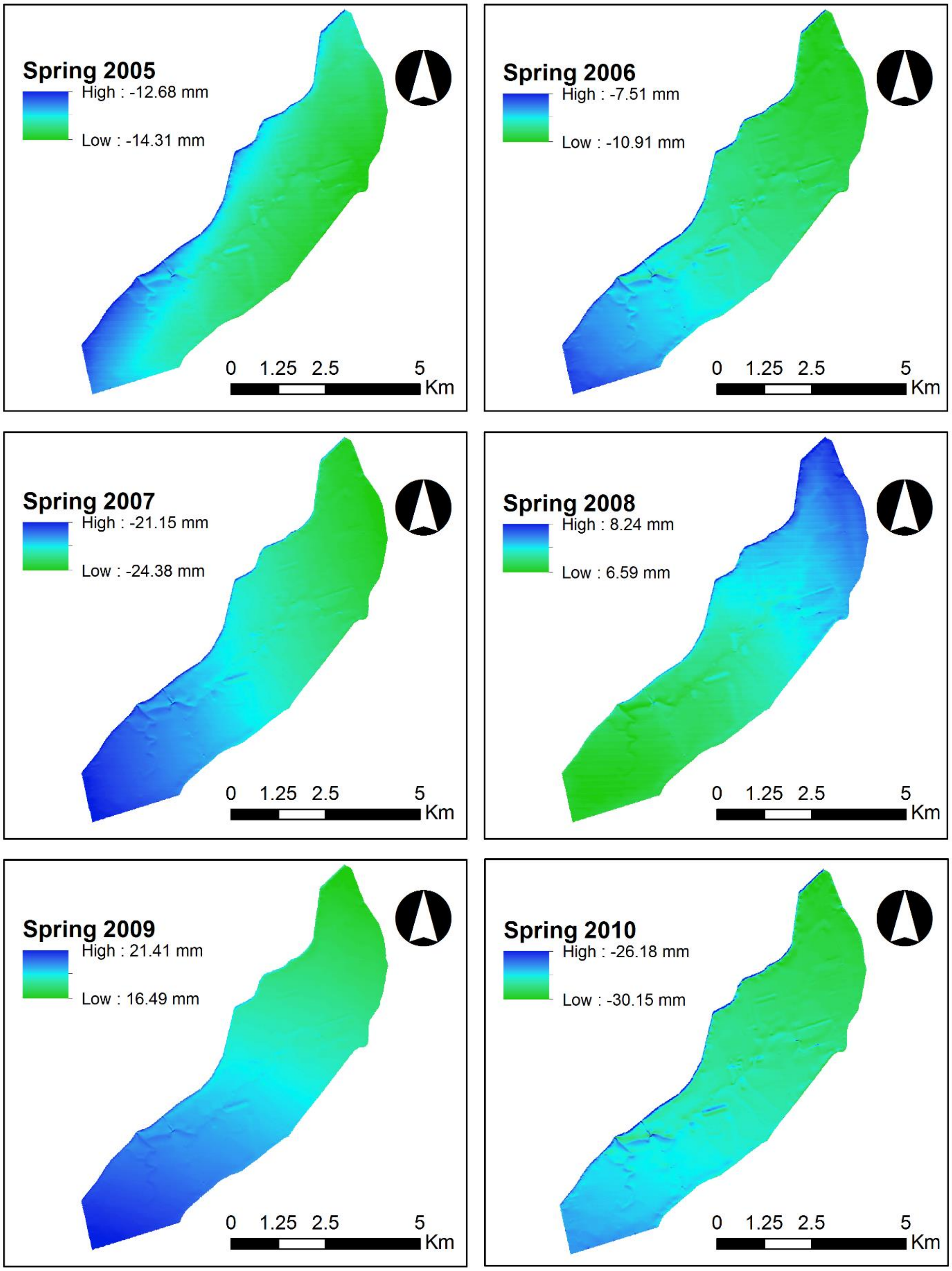


Figure 5-9: Spring Water Balance (2005-2010)

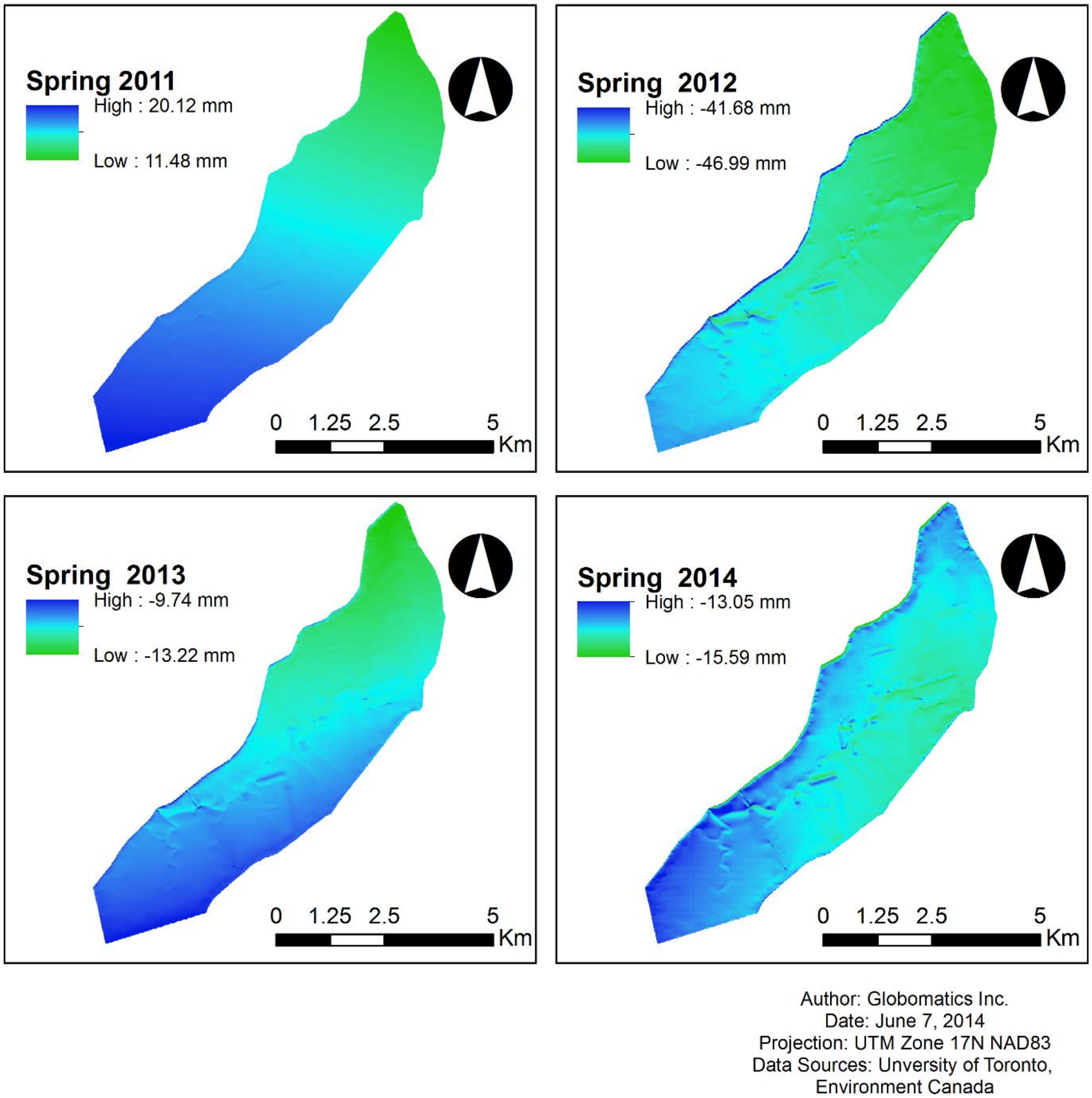


Figure 5-10: Spring Water Balance (2011-2014)

5.2.3 Summer

Summarized below is the water balance results for the summer season (Figure 5-11).

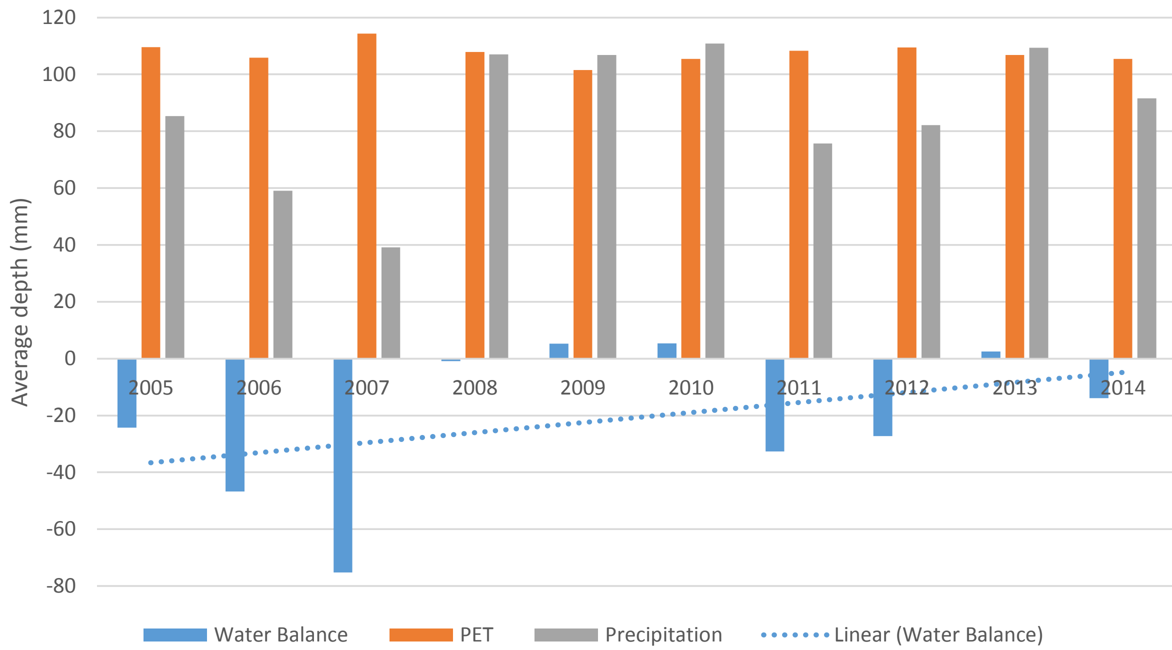


Figure 5-11: Summer Water Balance Summary

As depicted in the graph above, every year has produced a deceit in water balance (with the exception of 2009, 2010, and 2013). This again means the output of water in the system is greater than the input. The trend line suggests that there is an increasing trend of in water input in recent years causing the water balance to become more moderate. Overall, the average water balance for the summer in the past decade is calculated to be -20.78mm, with a standard deviation of 26.21mm. The minimum average water balance occurred during 2007, where a major flood struck the area, resulting in an average of -75.25mm across the Holland Marsh. The maximum water balance occurred during 2010 with an average of 5.35mm. The trend over the past decade has been a more moderate water balance, leaning towards a 0mm water balance. The results for the summer are visualized spatially in Figure 5-12 and Figure 5-13 on the following pages.

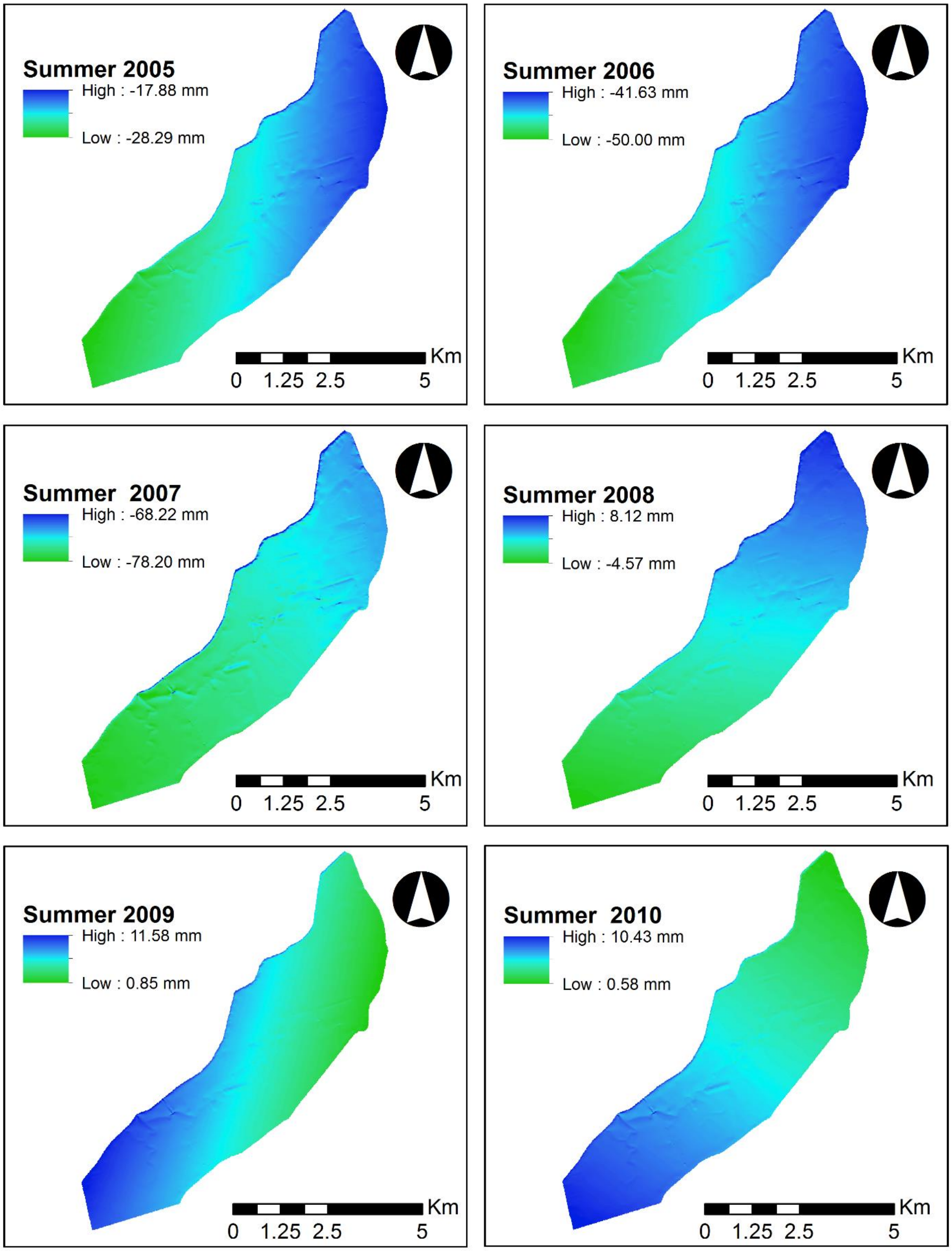


Figure 5-12: Summer Water Balance (2005-2010)

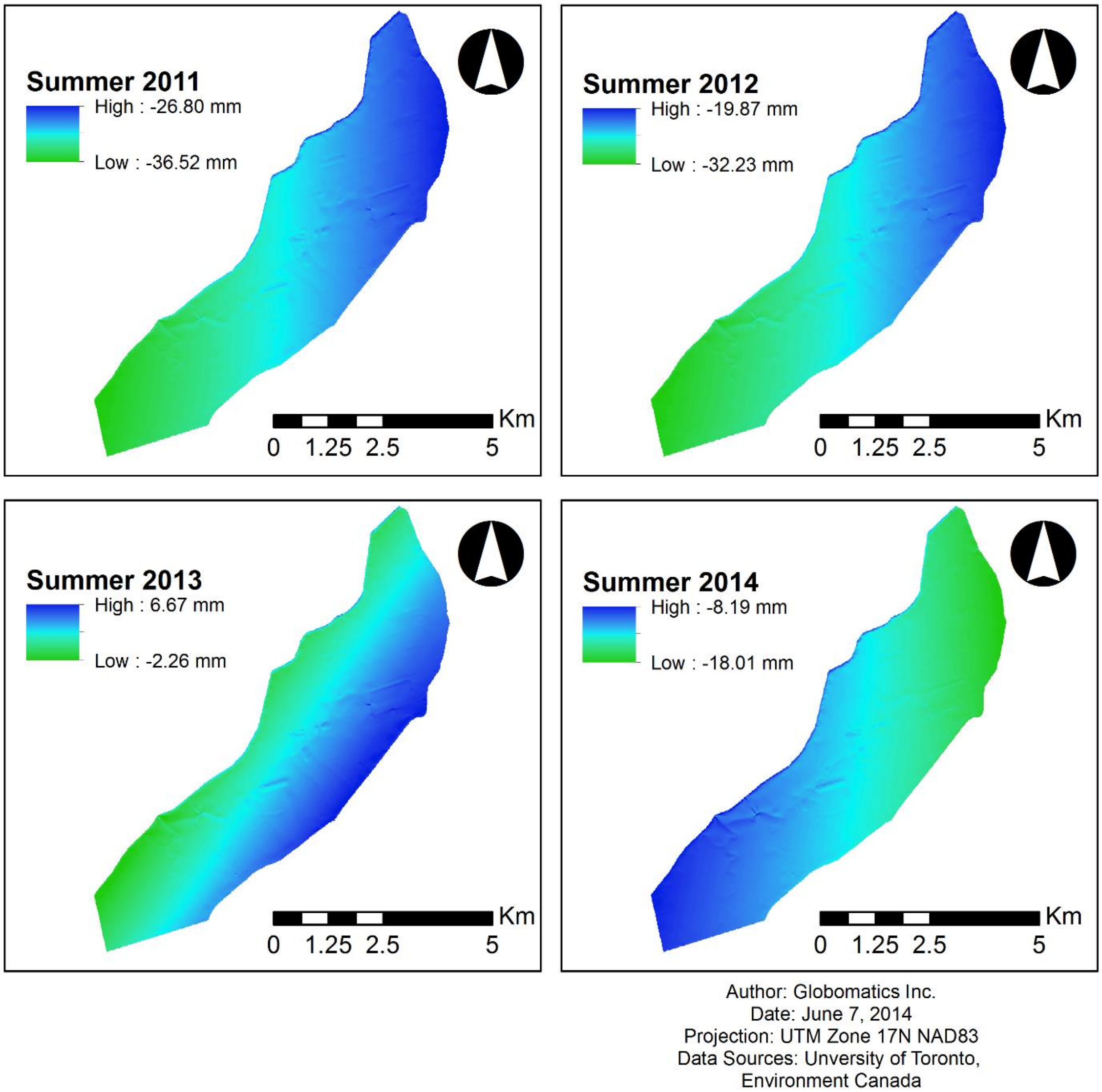


Figure 5-13: Summer Water Balance (2011-2014)

5.2.4 Fall

Summarized below is the water balance results for the fall season (Figure 5-14)

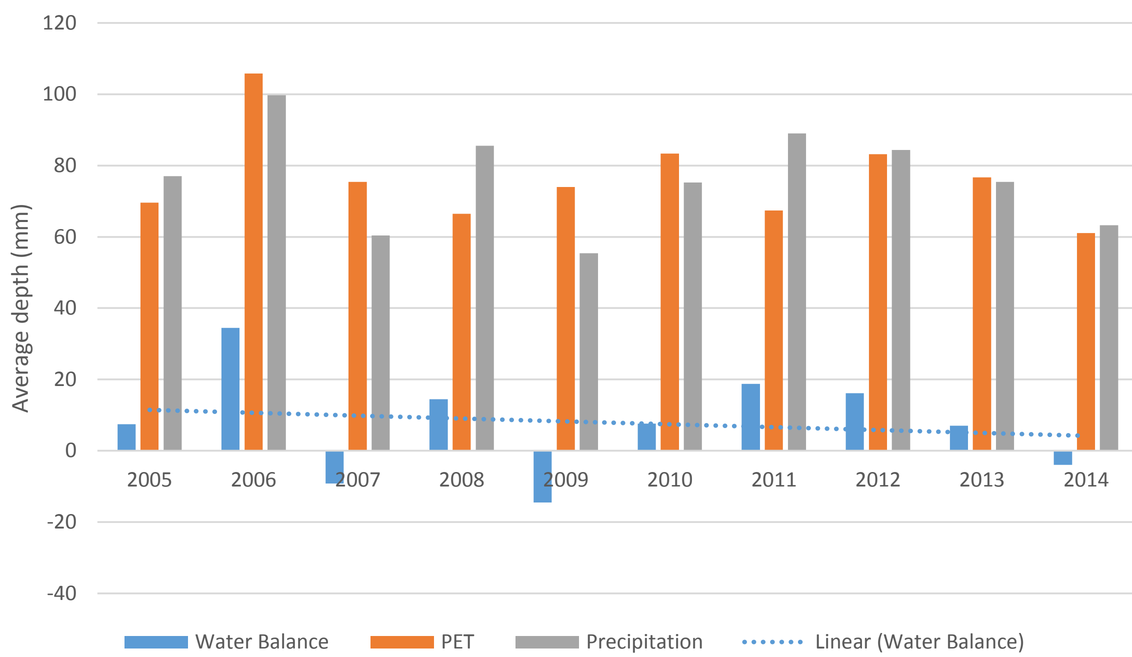


Figure 5-14: Fall Water Balance Summary

As depicted in the graph, the majority of years have produced a positive water balance (with the exception of 2004, 2007, 2009, and 2014). This means that precipitation is the more dominant variable, contributing more input than output to the system. The average water balance for the fall in the past decade is calculated to be approximately -7.83mm with a standard deviation of 14.41mm. The minimum average summer water balance occurred during 2009 with an average depth of 14.49mm with the maximum occurring during 2006 with an average depth of 34.36mm.

The results for the fall are visualized spatially in Figure 5-15 and Figure 5-16 on the following pages.

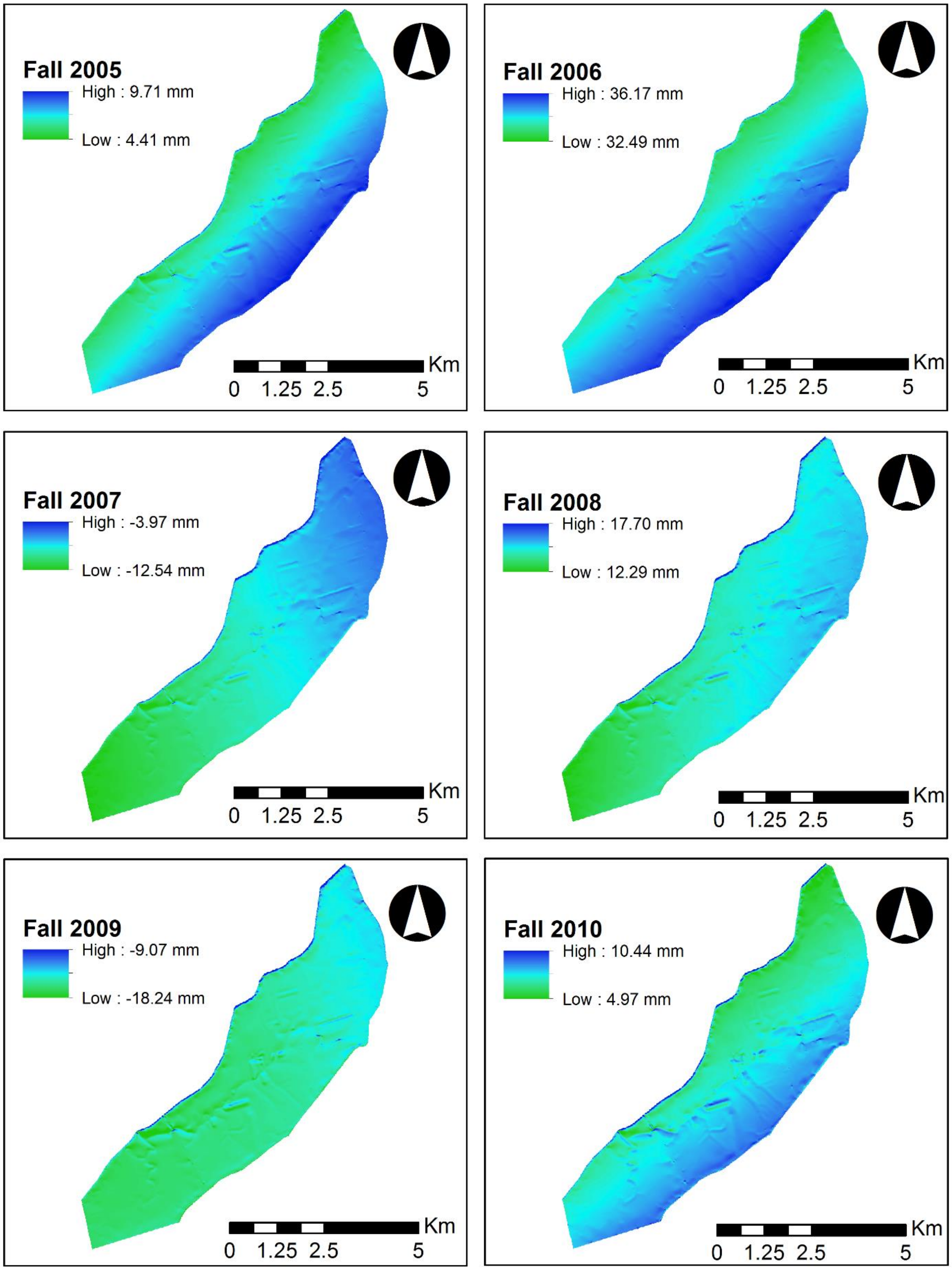


Figure 5-15: Fall Water Balance (2005-2010)

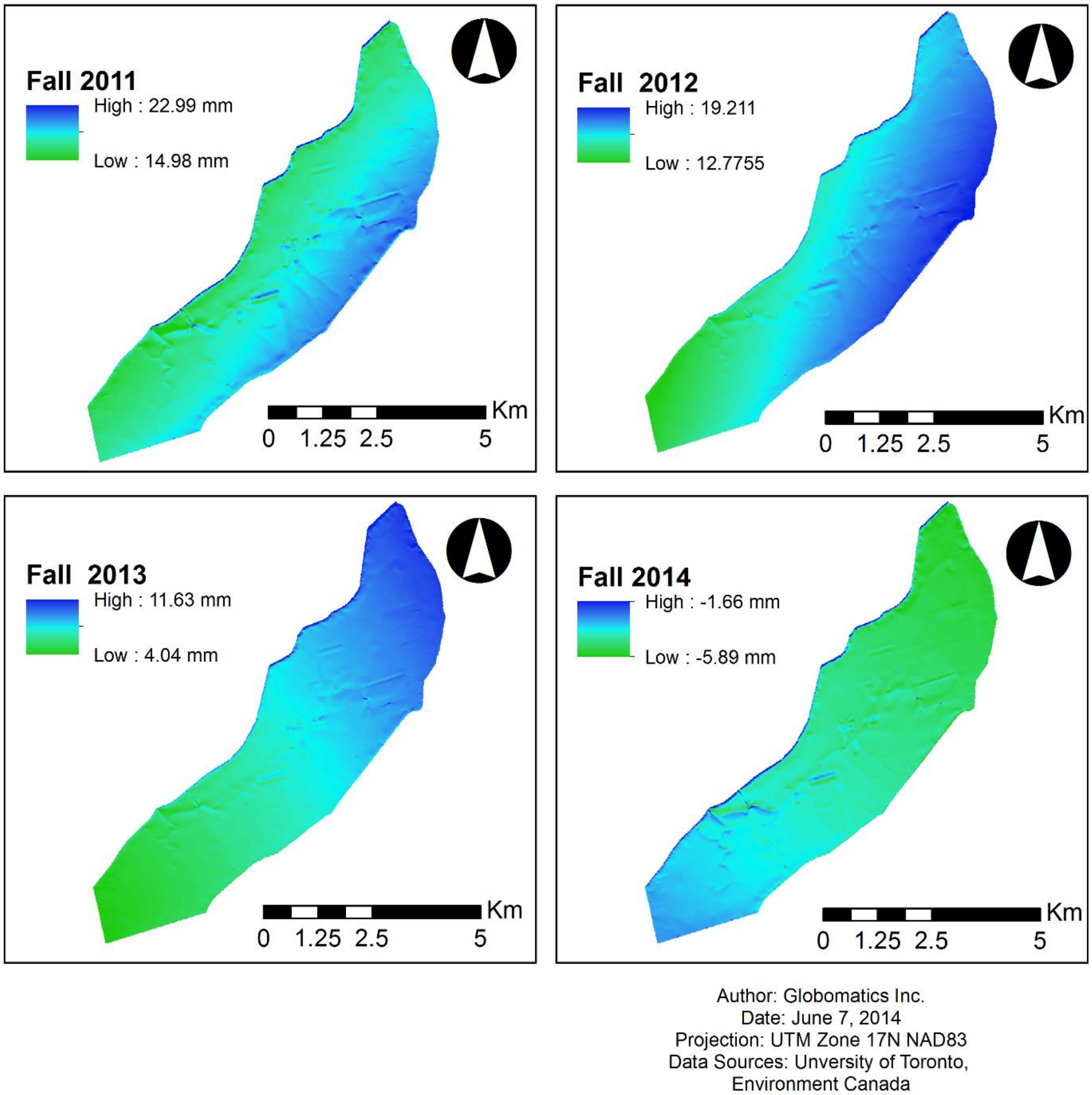


Figure 5-16: Fall Water Balance (2011-2014)

5.2.5 Growing Season

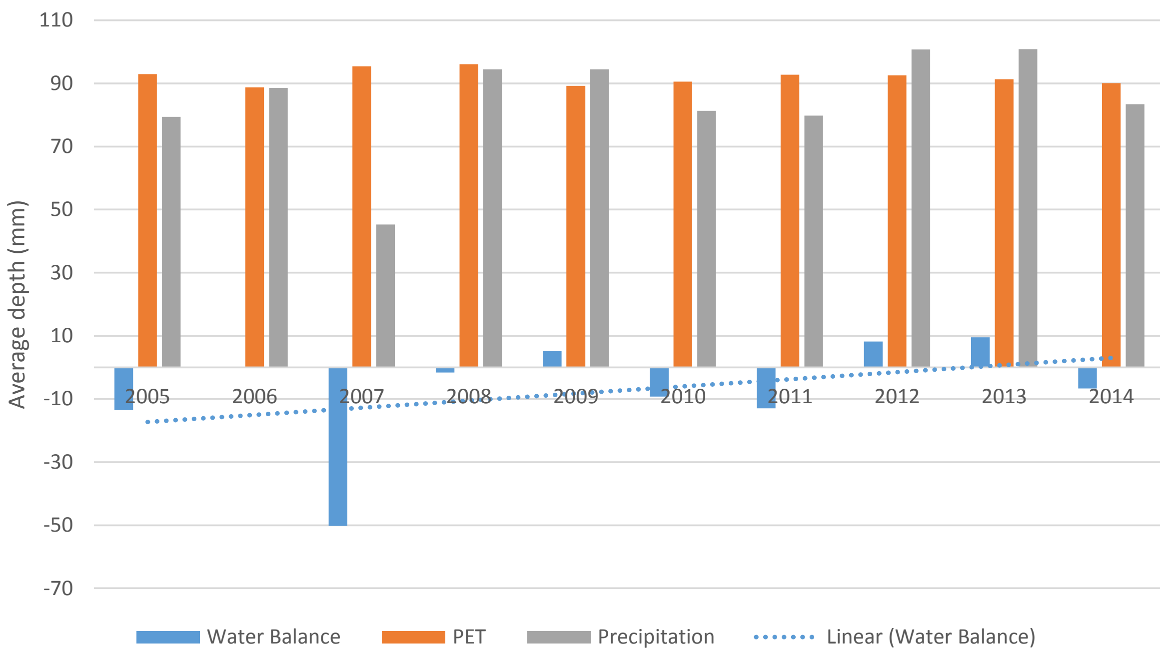


Figure 5-17: Growing Season Water Balance Summary

The most important season for the Holland Marsh, is the growing season due to the large profit made by harvesting crops. As depicted in the graph, the growing season has witnessed an increasing water balance trend over the past 10-year study period. The average water balance depth is -7.15mm with a standard deviation of 17.24mm. This negative value offers the farmers crop protection, and fields will not become over saturated and flood, however they will also need to irrigate more to maintain healthy crops. Another positive is the trend. The trend during the last 5 years has become more moderate, with a positive balance, but not witness to any extremes. The results for the growing season are visualized spatially in Figure 5-18 and Figure 5-19 on the following pages.

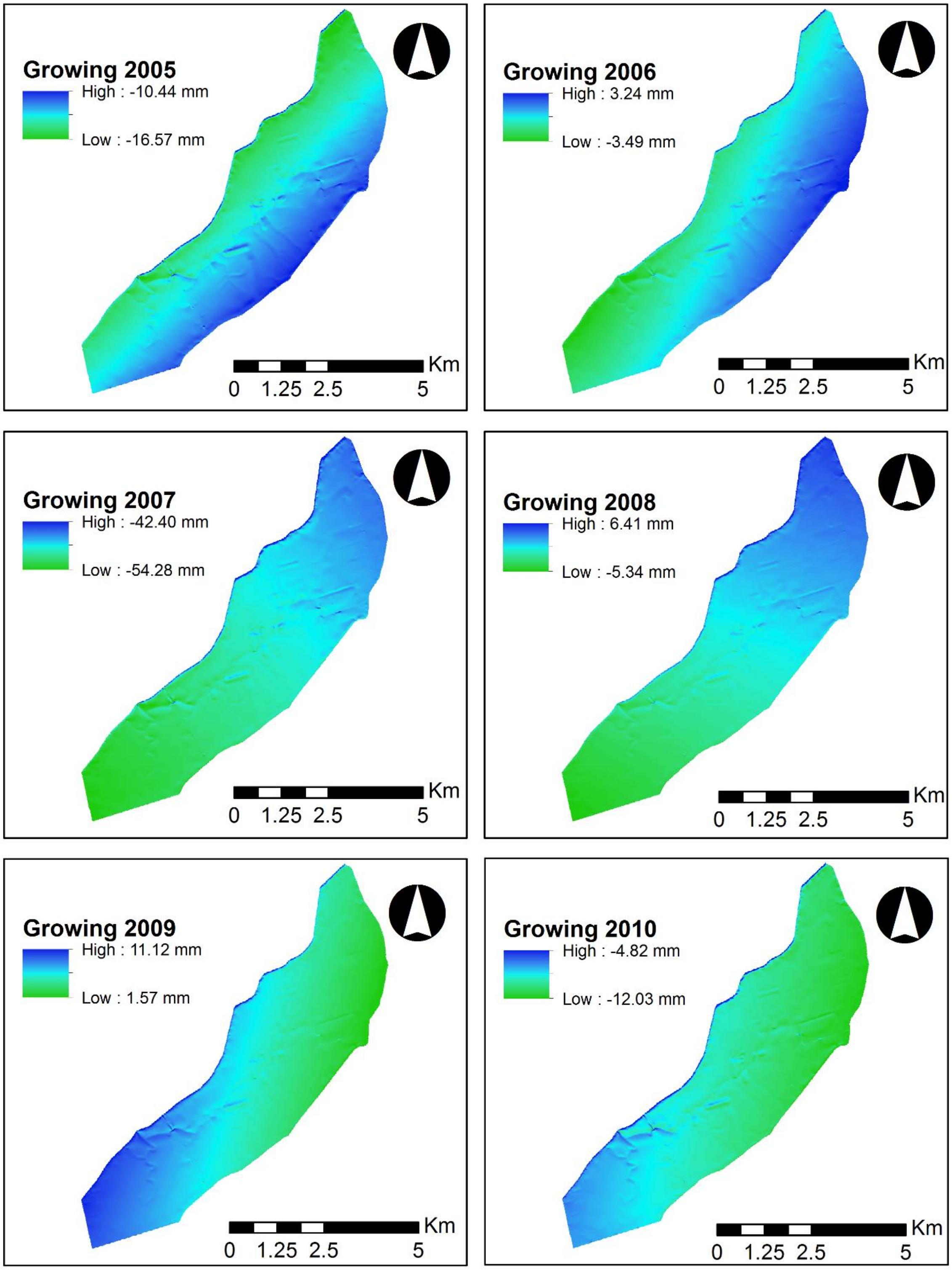


Figure 5-18: Growing Season Water Balance (2005-2010)

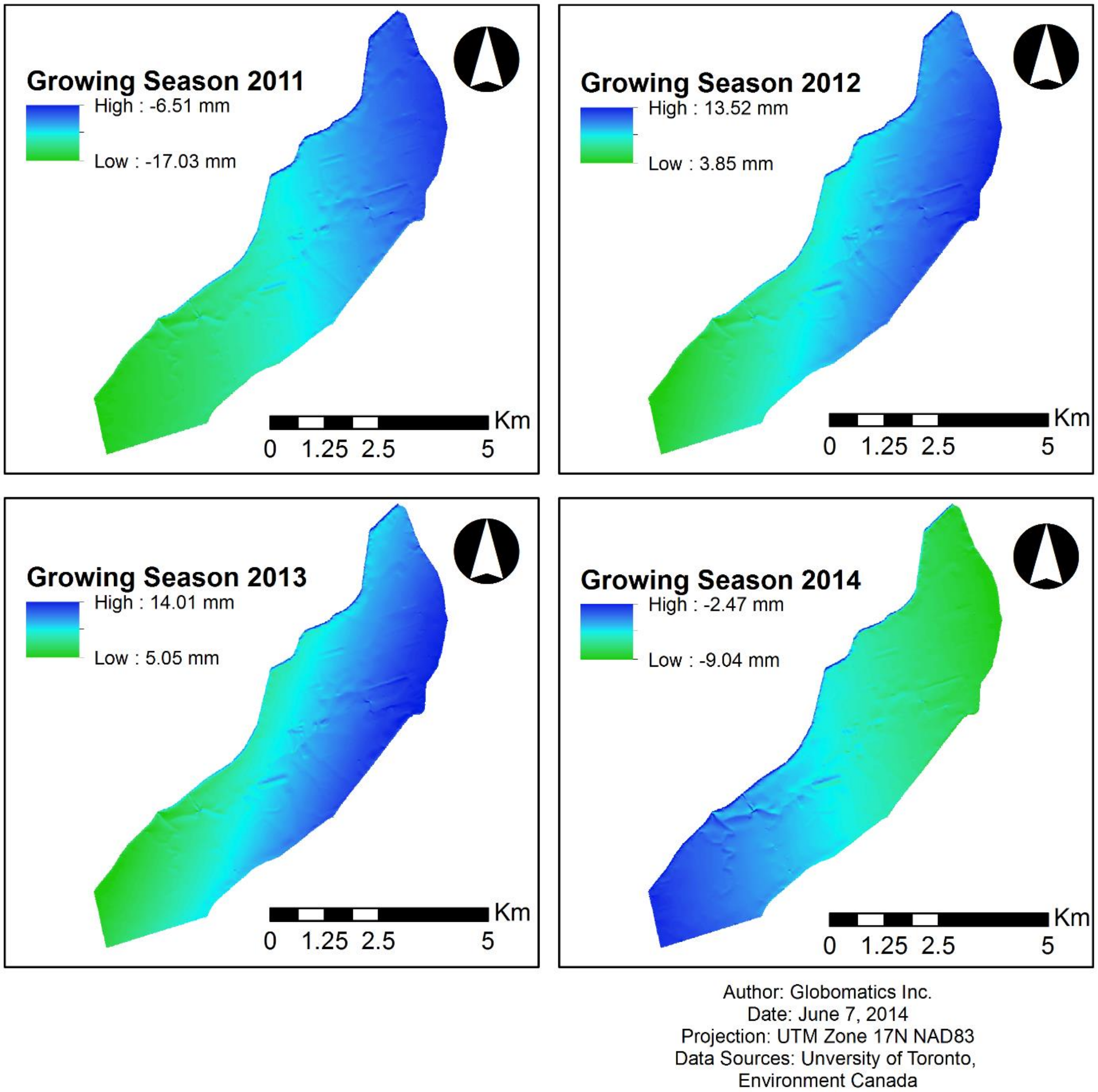


Figure 5-19: Growing Season Water Balance (2011-2014)

5.3 Holland Marsh Water Balance by Volume

The water balance of the Holland Marsh is summarized below in Figure 5-20: 10-year Water Balance by Volumes. This figure displays the volumes off the incoming precipitation (blue), the outgoing evapotranspiration (red) and their difference as the water balance (grey). These values have been calculated on a monthly basis for the total volumes across the Holland Marsh in cubic meters. Annual volumes are shown below in Table 7: Annual Water Balance by Volumes, and total monthly volumes displayed in Appendix E.

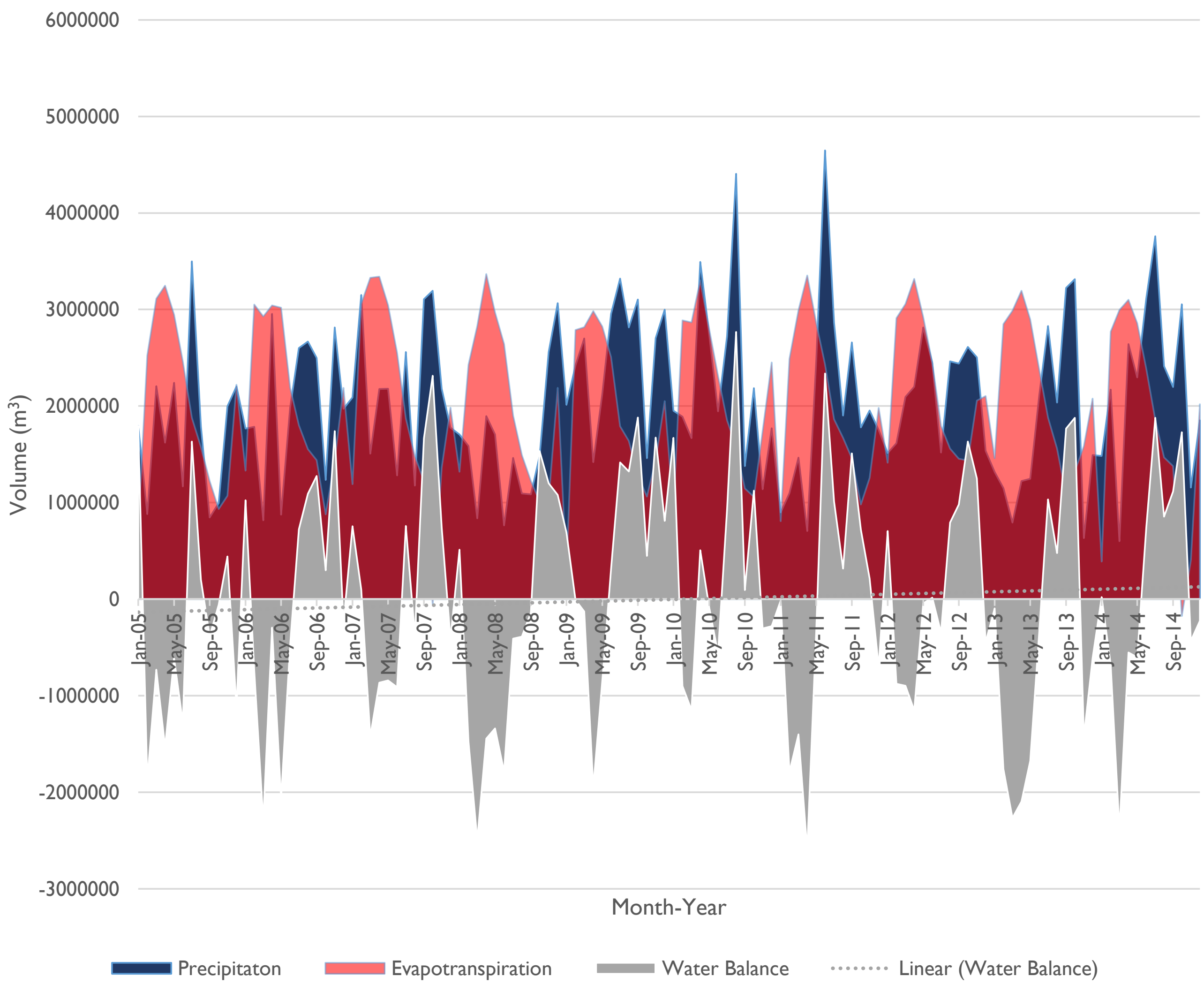


Figure 5-20: 10-year Water Balance by Volumes

Table 7: Annual Water Balance by Volumes

	Precipitation (m^3)	Evapotranspiration (m^3)	Water Balance(m^3)
2005	23,964,887.22	23,940,847.54	24,039.69
2006	26,375,564.96	24,863,022.87	1,512,542.08
2007	19,247,844.48	24,393,694.97	-5,145,850.50
2008	30,036,172.03	24,405,745.94	5,630,426.09
2009	27,286,016.67	23,468,162.59	3,817,854.07
2010	24,199,173.58	24,903,465.43	-704,291.85
2011	25,761,967.69	24,143,549.58	1,618,418.11
2012	21,372,302.49	26,471,576.84	-5,099,274.35
2013	26,738,949.23	25,272,569.24	1,466,380.00
2014	21,223,548.87	21,450,029.68	-226,480.81
Average	**24,620,642.72**	**24,331,266.47**	**289,376.25**

The annual average precipitation for the 10-year study period is 24,620,642.72 m^3 with a decreasing trend. The annual average evapotranspiration volume is 24,331,266.47m^3, also with an equal decreasing trend. These two variables results in an average annual water balance of 289,376.25m^3 with negative values for 2007, 2010, 2012 and 2014 stating that there is more water leaving the system then entering during those years.

6 Project Management

6.1 Schedule

This project was commenced in October 2014, with the final completion date set for June 2015 (Valenti & Rouque, Water Balance in the Holland Marsh: Project Proposal, 2015). Within this timeframe, a number of deadlines were met. The Project Proposal was completed in December 2014, followed by a Progress Report in March 2015 (Valenti & Roque, Water Balance in the Holland Marsh: Progress Report, 2015). This document comprises the Final Report, consisting of the final findings of the water balance. A complete schedule of the scheduled tasks and their revisions can be seen on the following page in Table 8.

Table 8: Project Schedule

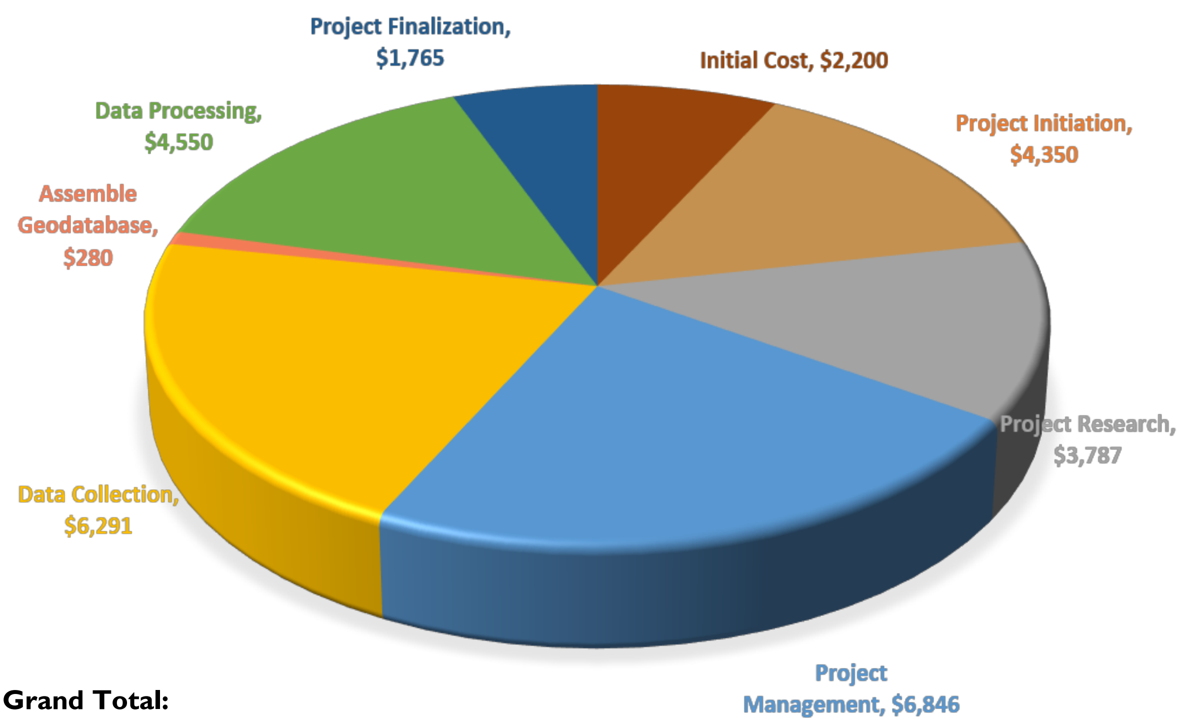
WBS	Task Name	Start	Finish	Revised Finish
1	**Holland Marsh Water Balance Project**	**10/15/14**	**6/19/15**	**6/12/15**
1.1	**Initial Costs**	**10/15/14**	**6/19/15**	**6/12/15**
1.1.1	Computers and Hardware	6/19/15	Fri 6/19/15	Fri 6/19/15
1.1.2	Stationary, Printing, Binding	6/19/15	Fri 6/19/15	Fri 6/19/15
1.1.3	Field Trip Expenses	6/19/15	Fri 6/19/15	Fri 6/19/15
1.2	**Project Initiation**	**10/15/14**	**12/5/14**	**12/5/14**
1.2.1	Project Kick-off Meeting	10/3/14	10/3/14	10/3/14
1.2.2	Project Overview Statement	11/10/14	11/11/14	11/11/14
1.2.3	Define Project Outline	11/26/14	11/27/14	11/27/14
1.2.4	Proposal Presentation	11/27/14	12/2/14	12/2/14
1.2.5	Proposal Report	11/28/14	12/5/14	12/5/14
1.3	**Project Research**	**11/28/14**	**1/27/15**	**3/10/15***
1.3.1	Site Field Trip	11/28/14	11/28/14	11/28/14
1.3.2	Background Literature Review	11/28/14	1/21/15	3/5/15*
1.3.3	Define Methodology	1/20/15	1/27/15	3/10/15*
1.4	**Project Management**	**1/8/15**	**6/19/15**	**6/19/15**
1.4.1	Advisor Meeting with Ian Smith (Bi-weekly)	1/8/15	6/19/15	6/19/15
1.4.2	Client Meeting with DIG (Bi-weekly)	1/9/15	6/12/15	6/12/15
1.5	**Data Collection**	**10/30/14**	**2/13/15**	**3/2/15***
1.5.1	Obtain Data from Client (DIG)	10/30/14	1/7/15	1/7/15
1.5.2	Collect Meteorological Data	12/12/14	1/12/15	3/2/15*
1.5.3	Organize/Quality Check Data	12/15/14	2/13/15	3/2/15*
1.6	**Assemble Geodatabase**	**1/16/15**	**3/20/15**	**3/31/15***
1.6.1	Create Basemaps	1/23/15	1/28/15	1/28/15
1.6.2	Design Geodatabase	1/22/15	1/26/15	3/31/15*
1.6.3	Progress Report Presentation	3/18/15	3/20/15	3/25/15*
1.6.4	Progress Report	3/16/15	3/20/15	3/25/15*
1.7	**Data Processing**	**3/26/15**	**5/29/15**	**5/29/15**
1.7.1	Create comparative maps and graphs of climate change	3/26/15	4/10/15	4/10/15
1.7.2	Define/Create Water Balance Model	5/11/15	5/20/15	5/20/15
1.7.3	Test Model	5/20/15	5/22/15	5/22/15
1.7.4	Execute Model	5/22/15	5/27/15	6/5/15*
1.8	**Project Finalization**	**5/27/15**	**6/12/15**	**6/17/15***
1.8.1	Climate change analysis	5/26/15	5/29/15	5/29/15
1.8.2	Report of analysis and methods used	6/1/15	6/10/15	6/10/15
1.8.3	Create maps and graphics	6/5/15	6/10/15	6/10/15
1.8.4	Final Presentation	6/10/15	6/12/15	6/10/15
1.8.5	Final Report	6/5/15	6/12/15	6/17/15
***Revised Dates.**				

6.2 Budget

Note: This Project Budget has been prepared for the learning purposes and in no way is the client expected to incur these prepared costs. The value of this project will be donated to the Drainage Investment Group (DIG) by the student consultants, Niagara College and the advisory staff.

As part of proper project management practices, a total budget was created to summarize the costs related to the time of work and resources used. Originally (Valenti & Rouque, Water Balance in the Holland Marsh: Project Proposal, 2015), the total budget was estimated to be a grand total of $44,400.00, including contingency and HST (13%). In March, this estimated budget was updated to be approximately $42,600.00 (Valenti & Roque, Water Balance in the Holland Marsh: Progress Report, 2015). After completion of the project, the total cost has come out to be roughly $30,000.00. This is $12,000.00 less than what was estimated.

Figure 6-1 displays a pie chart displaying the cost of each task and its contribution to the whole project cost.



Grand Total:

Project Cost + HST = $34,000.00

Figure 6-1: Final Cost Per Task

Earned Value Analysis

An earned value (EV) analysis was done to track the overall performance of the project, compared to the original budget. The planned value (PV) is referenced against the actual cost (AC) of the project, as the stages are completed, while displaying the overall EV (Figure 5-16).

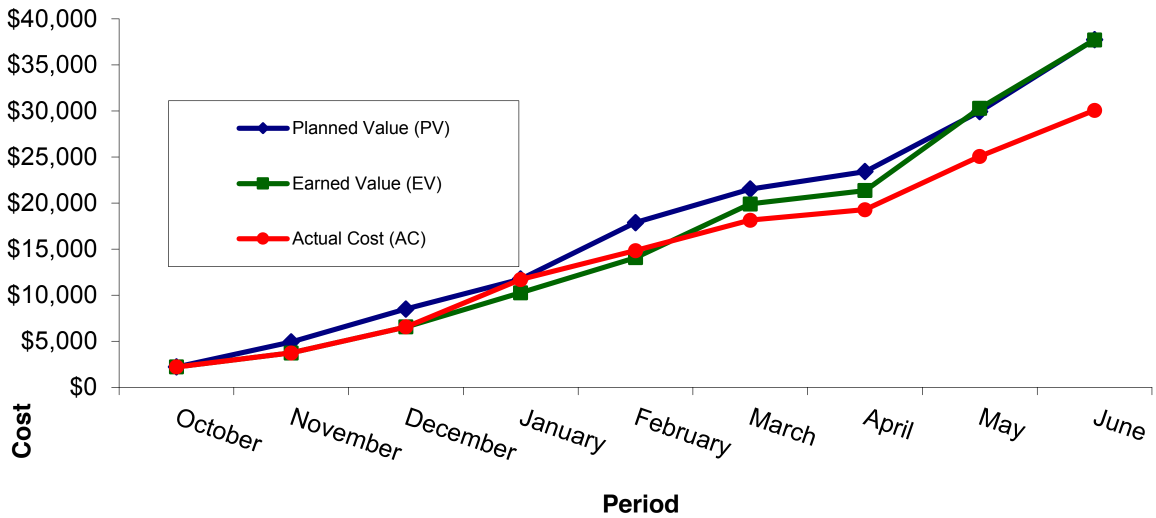


Figure 6-2: Earned Value Analysis

As shown in the chart, the PV depicts the original budget of the project on a monthly basis. The EV represents the progress of the budgeted cost of work performed. The AC shows the timeline of actual costs throughout the project.

January 2015 marks the only period in the project which the actual cost exceeded the planned value. This was due to more time spent on the data collection phase in order to collect the most effective data. To compensate for the additional time spent, the time for geodatabase creation was able to be shortened. This allowed for project completion on-time and under budget.

7 Challenges

7.1 Assumptions

Assumptions are specific circumstances or events which are critical for the success of the project. These events are expected to occur, increasing the chance of a productive outcome. Some of the main assumptions relating to this project included:

- Sufficient data were to be provided by DIG and Niagara College,
- Publically available climatic data were adequate enough for the scale of analysis,
- Project was able to be completed successfully within the given time period,
- Access to the GIS lab, necessary hardware, and software were provided by Niagara College, and
- Additional field work was not required for an effective water balance result.

7.2 Risk Management

Each project has some sort of associated risk. In the case of this project, intensive field work was not required, therefore most of the risks pertain to errors in software, data, or methodologies. These risks are detailed below:

- All software and hardware may crash, resulting in loss of work and/or data.
    - Proper use of software and constant back-up practices were maintained in order to avoid any set-backs in the project.
- Data provided and collected may have not been entirely correct, accurate, and/or precise.
    - Data quality checking was a crucial process, as any errors can be identified and remedied.
- Water balance methodology was to be carefully planned and initiated.
    - Research of suitable calculation methodology was done through academic articles.
    - Models were tested and run multiple times to improve the quality of output results.

7.3 Constraints

- All deliverables were to be completed by each set deadline.
    - Major Deliverables (presentations & reports) had scheduled due dates.
    - Entire project requirements were to be met before a final deadline in June 2015.
- Cost and time management was essential to keep project under budget and on schedule.
    - Initial proposed budget of $44,400.00 limited the amount of additional or incidental costs.
- Any trips to the Marsh was complicated by travel and time restrictions.
    - *In-situ* observations were valued and taken into account, due to this limitation.

8 Recommendations

Given the limitation of the source data, this study is conducted using a generalized water balance equation, interpreted as the difference between precipitation and evapotranspiration. A climatic water balance can be a much more complex process, with many more variables such as groundwater and soil storage. The next step of improving this model would be collection of these additional data to produce a more precise calculation.

Furthermore, the lack of weather stations in the Marsh led to interpolation of climatic data. The Holland Marsh contains a unique micro-climate due to its geographic placement. This means that the data interpolated is predicted, not definite values. For the generation of more accurate results it would be recommended that meteorological be derived directly from the study area.

Through further analysis of these water balance surfaces, detailed trends can be identified. The water balance model can be utilized for the identification of areas with deficit or excess of water. This is extremely useful for the implementation of future projects related to restoration or management initiatives.

Conclusions

The Holland Marsh is known to be of significant importance in terms of agricultural practices and growing fresh produce in Ontario. Analysis of climate data is important for the understanding of how historic trends has impacted the area.

A water balance model has been developed to calculate the total water balance over a ten year period within the Holland Marsh [2005-2014]. This model involved the use of a GIS environment for interpolation of climate data, along with the use of the map algebra to derive water balance surfaces. Categorized by season, month, and year, findings have been displayed statistically and visually.

A total budget was created to summarize the costs related to the time of work and resources allocated in project completion. The total cost of the project is $34,000.00, which is under the projected budget of $42,600.00 set in March 2015.

The findings found that the Holland Marsh is trending to becoming a more moderate micro climate, with increasing winter average temperatures, decreasing summer average temperatures. These temperatures are accompanied by an annual decrease in precipitation volumes, with more regular extreme events occurring (two 10-year events within the past 10 years). The average annual water balance for the study period was calculated to be an input of 289,376.25 m3 with a moderate decreasing trend.

Through investigation of the Holland Marsh, this study can be contributed to a much larger-scale project: preservation of the agricultural land. Globomatics Inc., in collaboration with the Drainage Investment Group and Niagara College, has provided an analysis for the benefit of any future river restoration and management initiatives. This water balance project had been completed successfully as of June 2015.

Acknowledgements

Globomatics Inc. would like to thank the following organizations and individuals who have contributed to this project throughout its duration. Without their knowledge, guidance, and support, this project would not be possible. A special thank-you also goes out to Erin Campbell, for making this project much more manageable and easy sailing.

Drainage Investment Group (DIG)

Niagara College Canada

Ian D. Smith, Project Advisor

Town of Bradford West Gwillimbury

Ontario Ministry of Agriculture, Farming, and Rural Affairs

11 Bibliography

Drainage Investment Group. (2014). Terms-of-Reference. Niagara Falls, Ontario, Canada.

Drainage Investment Group. (2015). Retrieved from Drainage Investment Group: http://dig.experienceonyx.com/

Environment Canada. (2015, January 25). Historical Climate Data [2004-2014]. Ontario, Canada.

ESRI. (2013, June 24). *ArcGIS Help 10.1*. Retrieved from ArcGIS Resources: http://resources.arcgis.com/en/help/main/10.1/index.html

ESRI. (2015). ArcGIS. Redland, California, USA.

Geovisuals . (2014). *Canadian Air photos/Aerial Images/Ground Images*. Retrieved from Geovisuals : http://geovisuals.smugmug.com/

Lake Simcoe Region Conservation Authority. (2013). *Annual Water Balances and Total Phospohrus Loads to Lake Simcoe (2007-2009).* Newmarket: Lake Simcoe Region Conservation Authority.

Ontairo Ministry of Natural Resources. (2015, January 25). Greater toronto Area (GTA) Orthophotography Project 2007. Canada.

Ontario Ministry of Agriculture, Food and Rural Affairs. (2013). *Going Forward Spring 2013*. Retrieved from OMAFRA: http://www.omafra.gov.on.ca/english/about/growingforward/2013-successstories2.pdf

Ontario Ministry of Natural Resources. (2006). Digital Elevation Model (DEM): 3091. Canada.

Planscape Inc. . (2009). *Holland Marsh Agricultural Impact Study.* Green Belt .

Smith, I. (2015). ENVR9174 - Deliverable #4: Ex-situ flow Analyses. Niagara-on-the-Lake, Ontario, Canada.

The Friends of the Greenbelt Foundation. (2015). *About the Greenbelt Foundation*. Retrieved from Greenbelt: http://www.greenbelt.ca/about_the_greenbelt

Toronto Sun. (2009). *Flood of '05 still haunts T.O.* Retrieved from Toronto Sun: http://www.torontosun.com/news/torontoandgta/2009/08/19/10509381-sun.html

Turc, L. (1961). Evaluation des besoins en eau d'irrigation, évapotranspiration potentielle. *Annales Agronomiques 12 (1)*, 13-49.

University of Toronto. (2010). Weather Data. Canada.

Valenti, J., & Roque, R. (2015). *Water Balance in the Holland Marsh: Progress Report.* Niagara-on-the-Lake: Niagara College.

Valenti, J., & Rouque, R. (2015). *Water Balance in the Holland Marsh: Project Proposal.* Niagara-on-the-Lake: Niagara College.

Walton and Hunter Planning Associates. (1999). *Greater Toronto Area - Agricultural Economic Impact Study.* Toronto, Ontario: Government of Canada.

Wypych, A. (2012). *Spatial Modelling of climatic water balance using GIS methods.* Krakow: Jagillonian University.

Appendix A: Monthly Precipitation

A

Table 9: Monthly Precipitation (mm)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
January	62.39932	73.71948	60.18597	71.09602	68.925	31.74896	53.475	46.54561	52.35642	59.86667
February	62.975	111.2212	55.95	85.49391	66.74647	38.725	57	40.63567	76.7	41.96822
March	28.83836	53.15889	29.55576	95.37534	58.8944	51.78664	74.02201	27.98145	21.16096	26.93603
April	104.2595	76.88115	66.92337	50.08241	123.3437	24.91405	77.69082	43.21087	93.32195	72.60149
May	30.9	76.91964	60.26381	75.1	96.6	87.35	99.38265	44.01584	81.06118	40.48483
June	69.93253	45.225	27.01589	104.375	68.725	164.169	86.45101	74.57387	109.9267	91.6472
July	91.775	90.39432	51.69213	117.2661	96.15	101.1187	53.59975	99.925	132.7628	104.0924
August	94.15474	41.57235	38.60021	99.40002	155.5798	67.125	87.00398	71.96162	85.24913	78.86188
September	88.16574	109.6255	38.35	109.575	48.67386	93.90394	86.20888	113.8259	77.6	87.23333
October	43.6159	112.7381	52.29459	51.59999	77.2308	62.875	92.31607	117.075	107.9041	63.23333
November	99.34659	76.91139	90.40544	95.47991	40.25	69.02432	88.44039	22.30703	40.83098	39.26266
December	69.57228	62.66295	108.1936	105.8885	62.55	61.875	54.22574	52.72091	65.43019	43.41905
Total (mm)	**845.9349**	**931.0301**	**679.4308**	**1060.732**	**963.669**	**854.6156**	**909.8163**	**754.7787**	**944.3044**	**749.6071**

Appendix B: Monthly Solar Radiation

B

Table 10: Monthly Solar Radiation (cal/cm^2)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average (cal/cm^2)
January	2738.78	3256.495	2357.992	1589.682	2738.78	2925.951	2738.78	3632.853	2808.682	2808.682	**2759.668**
February	4586.261	4586.261	4586.261	2692.419	4175.394	3706.331	3109.935	4272.877	4019.862	4019.862	**3975.546**
March	8818.38	8818.38	7268.202	7931.227	8818.38	8324.346	6771.654	8818.38	7931.227	7931.227	**8143.14**
April	11704.95	10882.06	9778.508	9778.508	10638.65	12353.46	8702.947	10882.06	10638.65	10638.65	**10599.84**
May	12216.47	16215.2	16618.59	11333.91	14391.28	13837.27	10658.62	13837.27	13837.27	13837.27	**13678.31**
June	13692.64	13055.55	16051.17	12645.72	12645.72	12645.72	13692.64	13692.64	13692.64	13692.64	**13550.71**
July	14441.86	12848.58	15961.51	15961.51	13583.74	14993.55	15124.2	14993.55	14441.86	14441.86	**14679.22**
August	12380.02	13268.47	13268.47	13268.47	11819	11155.04	11819	12380.02	12380.02	12380.02	**12411.85**
September	9108.432	7475.907	10087.86	11301.63	10087.86	8386.793	9108.432	9622.717	9108.432	9108.432	**9339.649**
October	5311.895	5311.895	4629.964	6527.046	5188.242	5420.415	5420.415	4629.964	5311.895	5311.895	**5306.362**
November	3633.286	2684.582	3073.802	3314.794	4011.709	4011.709	4011.709	3633.286	3633.286	3633.286	**3564.145**
December	2238.912	2558.292	2558.292	2238.912	2238.912	2238.912	2558.292	1799.27	2238.912	2238.912	**2290.762**
Total (cal/cm^2)	**100871.9**	**100961.7**	**106240.6**	**98583.83**	**100337.7**	**99999.49**	**93716.62**	**102194.9**	**100042.7**	**100042.7**	

Appendix C: Monthly Temperature

C

Table 11: Monthly Average Temperatures (°C)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average
January	-8.08035	-1.64013	-4.66079	-3.33119	-9.95466	-6.75326	-7.7053	-4.83E-02	1.267665	-9.52695	**-5.04332**
February	-4.99455	-5.36518	-9.05643	-6.2326	-4.31346	-4.71259	-6.00349	0.350769	-1.42301	-9.80393	**-5.15545**
March	-2.35016	0.166064	-0.5091	-2.82116	0.232111	3.419035	-1.52263	7.958512	1.722835	-5.68318	**0.061233**
April	7.307544	7.664227	5.758833	9.057367	5.96631	10.00157	6.735272	6.467064	6.318099	5.553032	**7.082932**
May	11.45714	13.89259	13.4109	11.1212	12.50243	15.39468	13.89561	15.9082	14.61584	13.10549	**13.53041**
June	21.67653	18.52131	19.75186	17.10883	16.76312	18.11553	18.28144	19.9919	18.12304	18.3607	**18.66943**
July	22.91588	22.78559	20.25923	20.9302	18.36007	22.4711	23.47871	22.96188	21.29153	18.80202	**21.42562**
August	21.47479	20.38172	21.20204	18.95903	19.72474	21.32832	20.8627	20.65213	19.8596	18.73177	**20.31768**
September	18.10624	14.68318	17.3475	16.05255	16.00788	15.51688	17.02538	15.64503	15.14229	15.47645	**16.10034**
October	10.60799	7.961919	13.31542	8.277077	7.860323	9.302272	9.732898	9.605186	10.7628	9.844577	**9.727046**
November	4.010561	4.814723	1.694234	1.87258	5.356774	3.738468	6.48603	3.501965	3.468811	1.118786	**3.606293**
December	-4.36479	0.711504	-3.95353	-4.38026	-3.31605	-5.4413	1.316982	1.758919	-6.23968	-1.08007	**-2.49883**
Average	**8.147235**	**8.714793**	**7.880014**	**7.217801**	**7.099132**	**8.531726**	**8.548633**	**10.39611**	**8.742485**	**6.241559**	

Appendix D: Monthly Water Balance

D

Table 12: Monthly Average Water Balance (mm)

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Average (mm)
January	36.09972	26.68098	18.06468	24.46101	58.99346	-0.49426	24.93996	-3.35121	0.773974	46.11483	**23.22831**
February	29.93901	80.14792	57.7432	49.68022	29.25129	1.308608	22.37647	-10.0788	29.8657	48.15764	**33.83912**
March	-9.02167	2.447194	-18.5526	58.99227	7.899956	-9.65863	29.69174	-44.6576	-34.8797	12.77514	**-0.49639**
April	25.85724	-0.37744	-3.1691	-27.1879	50.91854	-61.6923	7.714214	-31.0722	19.96663	1.310085	**-1.77322**
May	-58.2871	-30.8348	-47.8432	-10.644	-1.86071	-14.5647	11.415	-58.7391	-19.5233	-57.3099	**-28.8192**
June	-40.0099	-58.2083	-90.5608	4.463408	-30.7104	62.9266	-19.2627	-33.3737	4.431626	-14.1752	**-21.4479**
July	-22.88	-16.9955	-66.241	-1.60745	-9.22729	-15.4848	-64.7578	-17.2529	20.0017	-5.41239	**-19.9858**
August	-9.83423	-65.0434	-68.9615	-5.47159	55.84967	-31.3869	-13.9257	-31.1591	-16.9944	-22.0628	**-20.899**
September	1.268799	32.23207	-51.724	16.29816	-39.9019	12.31549	0.340482	27.43647	-6.2941	2.971154	**-0.50574**
October	-22.684	49.09663	-13.8324	-15.5916	14.01662	-2.49381	26.51565	53.68663	41.46671	-2.35794	**12.78224**
November	43.66994	22.08049	38.09532	42.7548	-17.5696	13.0962	29.47006	-32.7858	-14.2206	-12.6054	**11.19855**
December	26.3795	11.80516	64.97729	62.72967	17.25816	21.3162	2.701133	1.32638	27.24546	-5.29401	**23.04449**
Total (mm)	**0.497319**	**53.031**	**-182.004**	**198.877**	**134.9178**	**-24.8123**	**57.2185**	**-180.021**	**51.83975**	**-7.88871**	

Appendix E: Annual Water Balance by Volume (m3)

Table 13: Monthly Water Balance by Volumes (m^3)

Date	Year	Month	Precipitation (m^3)	Evapotranspiration (m^3)	Water Balance (m^3)
Jan-04	2004	1	1794963	1132.995	1793830
Feb-04	2004	2	879878.2	2751348	-1871470
Mar-04	2004	3	2206233	2935493	-729259
Apr-04	2004	4	1620001	3149286	-1529285
May-04	2004	5	2239786	2851852	-612067
Jun-04	2004	6	1169165	2449204	-1280039
Jul-04	2004	7	3499976	1866893	1633083
Aug-04	2004	8	1790956	1588705	202250.9
Sep-04	2004	9	847040.4	1228906	-381865
Oct-04	2004	10	994529.2	1050933	-56403.3
Nov-04	2004	11	1998694	1554714	443980.7
Dec-04	2004	12	2204099	3323669	-1119570
Jan-05	2005	1	1767746	744552	1023194
Feb-05	2005	2	1784040	2525565	-741525
Mar-05	2005	3	816971.1	3113418	-2296447
Apr-05	2005	4	2953589	3246787	-293198
May-05	2005	5	875376.6	2944836	-2069460
Jun-05	2005	6	1981133	2460908	-479775
Jul-05	2005	7	2599925	1877435	722490.1
Aug-05	2005	8	2667382	1576675	1090707
Sep-05	2005	9	2497730	1223058	1274672
Oct-05	2005	10	1235602	935389.3	300212.5
Nov-05	2005	11	2814451	1072028	1742423
Dec-05	2005	12	1970942	2220197	-249255
Jan-06	2006	1	2088431	1331974	756457
Feb-06	2006	2	3150826	3051381	99444.33
Mar-06	2006	3	1505958	2928990	-1423032
Apr-06	2006	4	2177990	3041103	-863114
May-06	2006	5	2179082	3019225	-840143
Jun-06	2006	6	1281194	2191654	-910459
Jul-06	2006	7	2560814	1802225	758588.7
Aug-06	2006	8	1177750	1552712	-374961
Sep-06	2006	9	3105624	1440162	1665462
Oct-06	2006	10	3193833	879788.4	2314044
Nov-06	2006	11	2178864	1436005	742858.5
Dec-06	2006	12	1775200	2187804	-412604
Jan-07	2007	1	1705026	1192722	512303.7
Feb-07	2007	2	1585027	3061356	-1476329
Mar-07	2007	3	837283.7	3329532	-2492248

Date	Year	Month	Precipitation (m^3)	Evapotranspiration (m^3)	Water Balance (m^3)
Apr-07	2007	4	1895901	3339663	-1443762
May-07	2007	5	1707242	3045965	-1338724
Jun-07	2007	6	765336.2	2550783	-1785447
Jul-07	2007	7	1464415	1872627	-408212
Aug-07	2007	8	1093510	1481305	-387795
Sep-07	2007	9	1086430	1223703	-137273
Oct-07	2007	10	1481456	-51087.2	1532544
Nov-07	2007	11	2561144	1362261	1198882
Dec-07	2007	12	3065075	1984864	1080211
Jan-08	2008	1	2013126	1320556	692569.5
Feb-08	2008	2	2420810	2428080	-7269.54
Mar-08	2008	3	2700628	2829286	-128657
Apr-08	2008	4	1418128	3366271	-1948142
May-08	2008	5	2126517	2969801	-843284
Jun-08	2008	6	2955462	2641452	314009.7
Jul-08	2008	7	3320497	1902751	1417746
Aug-08	2008	8	2814566	1493041	1321525
Sep-08	2008	9	3102704	1222104	1880600
Oct-08	2008	10	1461805	1014050	447755.7
Nov-08	2008	11	2703604	1030206	1673398
Dec-08	2008	12	2998325	2188150	810175.9
Jan-09	2009	1	1951667	280920.3	1670747
Feb-09	2009	2	1889992	2788210	-898218
Mar-09	2009	3	1667644	2815796	-1148153
Apr-09	2009	4	3491596	2984073	507522.7
May-09	2009	5	2735307	2824169	-88862.1
Jun-09	2009	6	1946004	2508355	-562352
Jul-09	2009	7	2722565	1790125	932439.9
Aug-09	2009	8	4405302	1637356	2767946
Sep-09	2009	9	1378240	1282514	95725.88
Oct-09	2009	10	2186838	1061695	1125143
Nov-09	2009	11	1139711	1444023	-304312
Dec-09	2009	12	1771153	2050926	-279773
Jan-10	2010	1	899002.7	912954.9	-13952.3
Feb-10	2010	2	1096529	2886015	-1789485
Mar-10	2010	3	1466380	2866969	-1400589
Apr-10	2010	4	705468	3301981	-2596513
May-10	2010	5	2473385	2789691	-316306
Jun-10	2010	6	4648604	2310459	2338145
Jul-10	2010	7	2863240	1851124	1012116

Date	Year	Month	Precipitation (m^3)	Evapotranspiration (m^3)	Water Balance (m^3)
Aug-10	2010	8	1900698	1583778	316920.1
Sep-10	2010	9	2658951	1148467	1510484
Oct-10	2010	10	1780356	1059508	720847.9
Nov-10	2010	11	1954519	1739987	214532.5
Dec-10	2010	12	1752040	2452532	-700491
Jan-11	2011	1	1514188	807855.5	706332.1
Feb-11	2011	2	1614001	2491060	-877059
Mar-11	2011	3	2096016	2993590	-897574
Apr-11	2011	4	2199887	3351633	-1151746
May-11	2011	5	2814121	2858139	-44017.5
Jun-11	2011	6	2447985	2431692	16293.31
Jul-11	2011	7	1517708	1863347	-345640
Aug-11	2011	8	2463586	1669951	793635.1
Sep-11	2011	9	2441090	1459040	982050.4
Oct-11	2011	10	2613677	980381.6	1633295
Nov-11	2011	11	2504263	1255292	1248971
Dec-11	2011	12	1535446	1981569	-446123
Jan-12	2012	1	1317985	1412929	-94944.8
Feb-12	2012	2	1150642	2909807	-1759165
Mar-12	2012	3	792312	3056850	-2264538
Apr-12	2012	4	1223560	3318246	-2094686
May-12	2012	5	1246342	2920203	-1673861
Jun-12	2012	6	2111629	2446387	-334759
Jul-12	2012	7	2829457	1795041	1034415
Aug-12	2012	8	2037673	1560106	477566.8
Sep-12	2012	9	3223139	1455361	1767778
Oct-12	2012	10	3315071	1436084	1878987
Nov-12	2012	11	631638	2057016	-1425378
Dec-12	2012	12	1492855	2103546	-610691
Jan-13	2013	1	1482525	1460663	21861.94
Feb-13	2013	2	2171822	2848344	-676522
Mar-13	2013	3	599197.4	2987398	-2388201
Apr-13	2013	4	2642491	3193162	-550671
May-13	2013	5	2295313	2895361	-600048
Jun-13	2013	6	3112705	2375778	736927.5
Jul-13	2013	7	3759394	1881341	1878053
Aug-13	2013	8	2413919	1558933	854985.7
Sep-13	2013	9	2197306	1081229	1116077
Oct-13	2013	10	3055388	1326180	1729208
Nov-13	2013	11	1156166	1586926	-430761

E

Date	Year	Month	Precipitation (m^3)	Evapotranspiration (m^3)	Water Balance (m^3)
Dec-13	2013	12	1852722	2077252	-224530
Jan-14	2014	1	1694996	389292.2	1305704
Feb-14	2014	2	1188241	2769343	-1581102
Mar-14	2014	3	762636	2996669	-2234033
Apr-14	2014	4	2055556	3100947	-1045392
May-14	2014	5	1146235	2858012	-1711777
Jun-14	2014	6	2594831	2386201	208629.7
Jul-14	2014	7	2947153	1857382	1089771
Aug-14	2014	8	2232805	1468770	764034.9
Sep-14	2014	9	2469825	1379410	1090414
Oct-14	2014	10	1790316	-175643	1965959
Nov-14	2014	11	1111638	400839.6	710798.7
Dec-14	2014	12	1229317	2018807	-789490

Appendix F: Terms of Reference

GIS Postgraduate Student/Consultant Project for

2014-15

Project ID: **201415-07** (for our office use only)

Contact Person & Organization Details

Contact Person Name:	Brett Ruck
Title:	Executive Director
Telephone:	289-296-0701
Fax:	
Email:	bruck@digcorp.ca
Organization Name:	Drainage Investment Group (DIG)
Address:	4321 Queen Street, Niagara Falls, ON, L2E 2K9
Website:	www.digcorp.ca
Date:	

Water Balance in the Holland Marsh

Project Details

Project Background

Project Problem/Opportunity: The Holland Marsh area is known as the "Salad Bowl of Ontario" producing over $1billion in revenue annually from what is possibly the most fertile soil in Canada. This area is made up of 125 farms covering 2900 hectares just 50km north of Toronto in Bradford, Ontario. The Holland River flows through the marsh and drains into Cook's Bay of Lake Simcoe. Of particular concern is the continued infiltration of nutrient contaminates.

Business Goal: To calculate the water balance of the Holland Marsh and identify areas of high susceptibility to nutrient intake.

Primary Project Objectives [Provide a list of the project objectives.]

- Undertake an analysis of climate data from the last decade to identify trends in climatic variables (Temperature, Precipitation, Storm Events, etc.).
- Identify potential areas of increased nutrient loading to the Holland Marsh River, mainly nitrogen and phosphorus.
- Identify the areas that have excess or deficit of water into the lower part (South-West) of the Holland Marsh River watershed.

Primary Project Deliverables [Provide a list of the project objectives.]

- Create comparative maps and graphs of climate change over the last decade.
- Undertake an analysis of climate change in the last decade and their impact on the Holland Marsh River.
- Performed detailed report of the analysis and methods used to calculate the water balance, including maps and graphics

Please fill-in all the yellow shaded boxes. For more information, please contact Janet Finlay (jfinlay@niagaracollege.ca).

For the Attention of the Students: This project will be used as part of the GIS postgraduate course GISC9302, GISC9309, and GISC9310. Forward letter of interest (including GIS project posting Number) and resume to Janet Finlay (jfinlay@niagaracollege.ca) via WORD attachment by **5 pm, Thursday, September 11, 2014**.

Requirements

Number of students required to complete the project:	2
Equipment required (if any):	None
Data required (if any):	DIG will provide data
Software required (if any):	ArcGIS, Office Suite
Confidentiality	TBD

Appendix G: Project Overview Statement

Project Overview Statement (POS)
Executive Summary

Project Name:	Water Balance in the Holland Marsh
Last Updated Date:	Tuesday, November 11, 2014
Author(s):	Josh Valenti, Ryan Roque
Project Manager(s):	Josh Valenti
Project Members:	Ryan Roque
Client Name:	Brett Ruck (Executive Director), bruck@digcorp.ca, 289-296-0701
Client Organization:	Drainage Investment Group (DIG)

Project Business Case

Business Problem/Issue/Opportunity
The Holland Marsh produces over one billion dollars in revenue annually, from what is possibly the most fertile soil in Canada. The wide variety of fresh produce grown in the area is the reason why it is referred to as the 'Salad Bowl of Ontario'. Located in Bradford, Ontario, the marsh covers 2900 hectares and contains about 250 farms. The Holland River is of particular significance because of its watershed, which flows through the marsh and drains into Cook's Bay of Lake Simcoe.
Project Business Goal
The overall goal is to calculate the water balance of the Holland Marsh and identify areas of high susceptibility to nutrient intake. This will be done by initiating an analysis of climate data in the Holland Marsh area. By investigating past climatic trends such as temperature, precipitation, and major storm events, the water balance can be calculated highlighting areas vulnerable to nutrient loading.

Primary Project Objectives

Primary Project Objectives

- Undertake an analysis of climate data from the last decade to identify trends in climatic variables (Temperature, Precipitation, Storm Events, etc.).
- Identify potential areas of increased nutrient loading to the Holland Marsh River, mainly nitrogen and phosphorus.
- Identify the areas that have excess or deficit of water into the lower part (South-West) of the Holland Marsh River watershed.

Project Benefits

Project Benefits

- Gain knowledge of climatic variables and water balance trends, for future analysis of areas with high susceptibility nutrient intake in the Holland Marsh River.
- Results may be used to develop future monitoring methods for water sustainability and prevention of high nutrient intake.
- Understand where and why the incoming and outgoing water flows in the Holland Marsh area, in order to sustain fertile soil for agricultural activities.

Primary Project Deliverables

Phase 1: Project Initiation

- Deliverable 1.1: Project Acceptance Confirmation (September 16, 2014)
- Deliverable 1.2: Project Kick-off Meeting (October 3, 2014)
- Deliverable 1.3: Project Overview Statement (POS) (November 11, 2014)
- Deliverable 1.4: Project Proposal Presentation (December 2, 2014)
- Deliverable 1.5: Formal Project Proposal (December 5, 2014)

Phase 2: Data Evaluation and Progress Report

- Deliverable 2.1: Data collection (November 2014 - April 2015)
- Deliverable 2.2: DIG Holland Marsh Site Visit (November 28, 2014)
- Deliverable 2.3: Bi-weekly status reports
- Deliverable 2.4: Project Presentation and Progress Report (March 2015)

Phase 3: Preparation of Final Report and Presentation

- Deliverable 3.1: Final Project Presentation (June 2014)
- Deliverable 3.2: Final Project Report (Hardcopy and digital) (June 12, 2014)
- Deliverable 3.2.1: Comparative maps and graphs of climate change over the last decade
- Deliverable 3.2.2: Analysis of climate change in the last decade and their impact on the Holland Marsh
- Deliverable 3.2.3: Details of analysis and methods used to calculate the water balance, including maps and graphics

Project Conditions

Project Assumptions and Risks

Assumptions:

- Data will be provided by Drainage Investment Group (DIG) and Niagara College.
- The objectives can be completed successfully within the course of each time period.
- Access to the GIS lab, hardware and software will be provided by Niagara College.
- Additional fieldwork is not necessarily needed for a successful analysis of the water balance.

Risks:

- All software packages and storage devices may crash, resulting in loss of work and/or data.

- The data provided and collected may not be entirely correct or accurate.
- Suitable calculation method of the water balance must be determined by researching academic articles.

Project Issues and Constraints

- All deliverables must be fully completed by the set deadline.
- Management of costs and time to keep project under budget and on time.
- Any additional fieldwork will be difficult because of time and travel restrictions.

Project Critical Success Factors (Key Performance Indicators)

Project Critical Success Factors

- Completion of reports, presentations and all other deliverables by each deadline.
- Excellent teamwork and communication between team members, project advisor and client.
- Understanding of the tasks required to efficiently and effectively meet each set objective.
- Full utilization of given resources (Personnel, software, data).

Project Duration Estimates

Project Phases	Date Estimate
Project Start Date	2014-09-16
Phase 1: **Project Initiation**	2014-09-16 – 2014-12-05
Phase 2: **Progress Report and Data Evaluation**	2014-11-01 – 2015-03-20
Phase 3: **Preparation of Final Report and Presentation**	2015-03-20 – 2015-06-12
Project End Date	2015-06-12

APPROVALS (sign on the dotted lines)

PREPARED BY -- **DATE** --

(PROJECT MANAGER)

APPROVED BY -- **DATE** --

(PROJECT / EXECUTIVE / CLIENT SPONSOR)

By signing this document, the above objectives, statements and dates have been agreed upon. However, due dates are only an estimate and are qualified to change based on certain situations and issues.

Refer to http://www.tenstep.com/open/miscpages/94.3Glossary.html for terms used in this document.

Appendix H: Gantt Chart

H