Modeling Streamflow and Salinity in the Mentor Marsh Watershed

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ABSTRACT

The Mentor marsh was the first declared National Natural Landmark in 1966 and became a nature preserve in 1971 in the State of Ohio. The Marsh was specifically dominated by catastrophic salt pollution due to the development of different human and industrial activities, especially during late 1950's to late 1970's. The Salinity is a crucial environmental problem in Mentor marsh leading to the profound consequences in wetland plants and aquatic habitats including the rapid development of *Phragmites australis* in downstream marshland. Consequently, disastrous loss of natural vegetation leading to the growth of more salt tolerant species such as Typha spp and *Phragmites australis* were experienced over the historical period, which were very vulnerable to capture fire. While several studies were conducted in the past in the Mentor marsh, hydrologic investigation of the watershed has not been conducted yet. It is because of the lack of monitoring stations and long-term data records. Since, Mentor marsh watershed is a small ungaged watershed and data are being collected for a short duration, the prediction of flow with limited data invites certain degree of uncertainty. Therefore, monitoring stations were established in two small tributaries of Blackbrook Creek and Marsh Creek, for real time data recording of flow stage, water conductivity, water temperature, and atmospheric pressure in hourly mode using Levellogger and Barrologger. Similarly, Creek cross-section, water velocity and water stage were recorded intermittently with direct field observation to develop a rating curve and generate the continuous streamflow data.

The hydrologic model, Soil and Water Assessment Tool (SWAT), was developed using climate data from National Climatic Data Center (NCDC) and DEM, land cover and soil

data from United States Department of Agriculture (USDA). The model was calibrated in monthly scale with good Nash Sutcliffe Efficiency (0.86), Root Mean Square Error (0.87) and Percentage bias (-2.9%) using the observed data from Blackbrook monitoring station from the period of November 2016 to August 2017. Similarly, it was validated with NSE (0.78), R^2 (0.87) and PBIAS (-13%), respectively using the observed data records from the period of September 2017 to March 2018. The total monthly salinity loading from Blackbrook Creek was in the range of 10.23 ton to 163.98 ton, whereas it was in the range of 65.63 ton to 2028.13 ton in Marsh Creek. The median monthly salinity loading in Blackbrook Creek and Marsh Creek were 55 ton and 329 ton, respectively. The analysis showed that the Marsh creek had higher salinity loading than that of Blackbrook creek during direct field observation. This was mainly because of the relatively large size of Marsh Creek catchment compared to Blackbrook Creek. However, the salinity concentration was higher in Blackbrook Creek compared to the Marsh Creek except in the month of winter and early spring seasons. The salinity loading was linearly correlated with streamflow in daily (R^2 = 0.72) and monthly scale in Blackbrook Creek (R^2 = 0.83). Similarly, the daily and monthly R^2 of streamflow with salinity in Marsh Creek was 0.86 and 0.76, respectively. Furthermore, the correlation of salinity loadings with simulated streamflow from SWAT model was utilized to generate the salinity loadings in streamflow events of various years at historical period. The monthly simulated salinity loading in Blackbrook and Marsh Creek in the historical period (2000-2016) illustrated that Marsh Creek contributed more than 10 times higher salinity loading than that of Blackbrook Creek. Similarly, the result showed that Blackbrook and Marsh Creek had higher median salinity loading in spring season. The salinity loading simultaneously decreased in summer

and fall in both Creek and vice versa in winter season, especially due to the road salt application. The result also showed that wet years 2008 and 2011 experienced higher salinity loading in both Creek. Likewise, the analysis showed that annual median salinity loading in a historical period of 2000 to 2016 from Blackbrook and Marsh Creek were 620 ton and 8334 ton salt load respectively, which contributed to downstream marsh.

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LIST OF ABBREVIATIONS

ARS	Agricultural Research Service
GIS	Geographic Information System
HRU	Hydrologic response units
LCSWCD	Lake County Soil and Water Conservation District
NCDC	National Climatic Data Center
NLCD	National Land Cover Dataset
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSE	Nash-Sutcliffe's Efficiency
ODOT	Ohio Department of Transportation
OEPA	Ohio Environmental Protection Agency
PBIAS	Percentage Bias
PSU	Practical Salinity Unit
RMSE	Root Mean Square Error
RSR	RMSE Standard Deviation Ratio
SSURGO	Soil Survey Geographic
STATSGO	State Soil Geographic
SWAT	Soil and Water Assessment Tool
TEOS	Thermodynamic Equation of Sea Water
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey

Chapter 1

Background

Mentor Marsh, located adjacent to Lake Erie in Northern part of Ohio, once was an exceptional natural landmark (Bernstein, 1977) . It was deemed as a first National Natural Landmark in 1966 and became a first state nature preserve on the Great Lake shoreline in 1971 (Matson et al., 2017). From the last few decades, Mentor Marsh was dominated by catastrophic salt pollution especially due to the development of different human and industrial activities, specifically during 1959 to late 1970's. In those period, it was reported that water salinity varied from oligosaline (500 to 5,000) mg/l to hypersaline (above 40,000 mg/l) (Fineran, 2003). This led to disastrous loss of natural vegetation leading to the growth of more salt tolerant species such as *Phragmites australis* (commonly called reed, giant reed and giant reed grass). The earlier study conducted by researchers (Rand 1968; Hauser 1972 Jones, 1975; Lass, 1984) in Mentor Marsh showed that the rapid growth and development of phragmites were due to the salt pollution by different anthropogenic activities within the vicinity of marsh land. The major pollution sources, which triggered the fresh water Marsh into salt stressed Marsh, are especially wind-blown salt, old brine well fields at the upstream of Blackbrook creek, downstream salt fill over Blackbrook creek and road salt application (used as a deicing agent during winter season).

For the first time in 1959, Headland Beach State Park rangers observed the wind-blown salt coated over the elm-ash-maple forest trees of the eastern basin and noticed that those plants were started dying (Fineran, 2003; Whipple, 199). Later, it was investigated and resulted that the Fairport Harbor salt mine associated with Mortan salt company was the source for wind-blown salt (Fineran, 2003).

The second source of salt pollution on Marsh was from Diamond Shamrock's Alkali facility. At the beginning of 1955, company built their brine well fields outside the Mentor Marsh Watershed adjacent to Grand River but later around 1955, they started constructing brine wells inside the Mentor Marsh watershed. During the mining process, they encountered with weak brine with almost zero industrial value and was dumped near by the facility. As a result, it entered inside the Blackbrook creek and flowed into the Marsh (Fineran, 2003). This facility announced to shut down their brine well fields with in the vicinity of Blackbrook watershed in 1977 (Bernstein, 1977).

The third source of salt pollution was from salt fill over Blackbrook creek. In between the first half of 1960's, this salt fill site was constructed on local owners land to deposit the low grade salt ore: generated by Fairport Harbor salt mine (Ohio EPA, 1980). A culvert was laid under the salt fill to collect and route the Balckbrook flow to dispose the water in Mentor Marsh. Approximate, 2×10^5 tons of salt residuals was dumped at the salt fill near the end of 1966. The leachate coming from old salt fill was collected and routed through the Blackbrook flow to dispose in Mentor Marsh. After 22 years of continued public concerns and appeals, Blackbrook was rerouted to flow east of the salt fill in 1988 (Fineran, 2003).

However, the study conducted by Rand (1969) and Jones (1975) suggested that the intrusion of salt pollution was primarily from two sources. One of which was from the location, where brine well fields were drilled, whereas the second source of salt contamination was from a previous salt dumping site. In both study, salt fill site was examined as the primary source of salinity in Marsh. They reported the data with maximum chloride levels of 97×10^3 mg/L at salt fill site (Rand, 1969). Similarly, Jones (1975) reported that the chloride concentration varied significantly when the Blackbrook creek flowed through the culvert. This was because the culverts cap was broken and allowing salt contaminated seepage water to be discharged into the Blackbrook Creek. When water passes through this soil substrate, the salt concentration can increase significantly up to twenty times (Rand, 1969). Therefore, later it was assumed that the major source of salinity in Mentor Marsh was only due to salt fill dumped over Blackbrook Creek. Currently, a housing development encompasses over salt fill area.

Whipple (1999) conducted a study after the Blackbrook was rerouted in 1988 and found the reduction in water salinity. Yet, the leaching through the brine well is still persistent and contributes to the stream salinity from storm water and ground water movement through salt fill.

While salinity investigations have not been conducted in ungaged watersheds, several scientist studied the salinity relationship with flow across the world using various modeling approaches. Some researches in the past have been conducted to comprehend salinity modelling by using various empirical models (Wang et al., 1992; DeSilet et al., 1992), statistical models (Gibson and Najjar, 2000; Prairie et al., 2005), hydrologic models (Gibbs et al., 2011; Michot et al., 2015; Mittelstet et al., 2015) and hydrodynamic models (Mohd et al., 2015; Meselhe and Noshi, 2001). Every models are composed of many variables that are difficult to analyze and execute (Gibson and Najjar, 2000). Moreover, developing a model to predict salinity in an ungaged catchment is a challenging job due to lack of information about the water quality and quantity data. Since the hydrological models does not simulate salinity, the development of a regression equation between streamflow and salinity could be a better option to predict salinity loading with respect to model predicted flow. Dawes et al. (2004) conducted a study in the unregulated catchment and concluded that the salt load from the small upland catchment was linearly related to the streamflow rate. Similarly, Mittelstet et al. (2015) conducted a study in North Fork river basin of United States using SWAT model and developed a regression equation between streamflow and electrical conductivity to predict salinity level. Similarly, Somura et al. (2009) used SWAT model and regression equation to study the salinity in Lake Sinji, Japan. Likewise, Gassman and Yingkuan (2015) also supported the fact that salinity modelling could be done by using simulated flow from SWAT model.

Several studies which were conducted across the world (Gikas et al., 2009; Piman et al., 2013) also used model simulated flow from SWAT with other salinity modelling tools and regression equation to predict salinity loading. These studies showed that simulated streamflow derived from the model was successful to correlate the salinity level to predict salinity loading for various climates from different parts of the world (Akhbari et al., 2014). Therefore, a hydrological model (Soil and Water Assessment Tool) SWAT has been utilized in this study to predict the salinity variation with respect to streamflow in current and historical time period.

The specific objective of this research project are:

1. To develop a hydrologic model to predict salinity loadings from the upland watersheds in various temporal scales such as hourly, daily, monthly and seasonal scale.
2. To determine salinity loading from the two tributaries in various temporal scales in the historical period with the help of simulated streamflow from the SWAT model.

Following methodology were completed to accomplish specific objective 1.

I. Download digital elevation model (DEM) to delineate the study area;

II. Delineate the watershed including land catchments, flow direction and accumulation, stream network, subbasin parameters, outlets in monitoring station and with outlet of whole watershed;

III. Download the necessary land use data, soil data and meteorological data and prepare the input data for SWAT simulation;

IV. Run the SWAT model for simulated stream flow;

V. Measure stream cross-section, velocity and stage for observed flow;

VI. Prepare stage discharge curve to interpolate daily and monthly flow calculation;

VII. Compare the observed and simulated flow and re-run the model if necessary for the model calibration and validation;

VIII. Install Levelogger in the Blackbrook creek and Marsh creek to record the real-time data of water level, stream temperature and conductivity;

IX. Install Barologger nearby Blackbrook creek to monitor atmospheric pressure and temperature for barometric correction on water level measured by Levelogger;

X. Download the data from Levelogger and Barolloger to prepare daily and monthly discharge records and salinity;

XI. Compare and analyze the hourly, daily and monthly salinity in both streams;

XII. Develop a correlation equation between observed discharge and salinity loading in both streams.

Following methodology were completed to accomplish specific objective 2.

I. Download the historical rainfall and temperature data from nearest weather station;

II. Re- run the calibrated and validated SWAT model in a historical time period;

III. Compare and analyze the daily, monthly, seasonal and annual salinity loading in both streams for historical time period.

Materials and Experimental Methods Used for Discharge and Salinity Prediction

The monitoring sites were established in Blackbrook and Marsh Creek by installing the Levelogger and Barologger instruments in order to record the real time data of stage, stream temperature, atmospheric pressure and conductivity. In the meantime, stream cross sections and flow velocity were recorded intermittently to develop the rating curve of observed flow vs stage datasets. Some of the pictures of the site monitoring has been in included in the Appendices. These observed data were utilized to calibrate and validate the SWAT model. In the next step, the simulated flow from SWAT model was utilized to develop a correlation equation between streamflow and salinity loading and predict the salinity loadings in current and historical time.

Study Area

The Mentor Marsh watershed (Figure 1.1) is located adjacent to the mouth of old Grand River at southern margin of Lake Erie, approximately 30 miles east from downtown Cleveland, Ohio. The watershed covers an area of approximately 20.32 square miles. It is the largest marsh in northeast Ohio and covers 1.08 square miles (Whipple, 1999). The marsh is 4.28 miles long, 0.5 mile wide at its widest point and has an approximate perimeter of 12.42 miles (Matson et al., 2015). The watershed lies between latitudes 410 39’ 18” N to 410 45’ 3.6” N and longitudes 810 22’ 26.4” W to 810 14’ 52.8” W. Similarly, the elevation of the watershed ranges from 172ft to 411ft above the mean sea level.

The climate of the watershed is humid continental climate with an annual average precipitation of 39 inches, whereas the average snowfall is 36 inches. The average annual high and low temperature are 58.90 ^{o}F and 43.60 ^{o}F, respectively. The marsh can be physically characterized as three basins such as east, west and middle. Hydrological flow within and between these basins involves inputs from Lake Erie and two sub-watersheds with creeks that enters the marsh. However, this study will be focused within targeted upland sub watersheds of the Mentor Marsh watershed. This watershed is further divided into two sub watersheds named as Blackbrook and Marsh Creek. Blackbrook is the smallest watershed amongst the two, which drains 2128.11 acres, whereas Marsh Creek is relatively larger watershed, which drains 8859.26 acres. In addition, Marsh Creek has two large tributaries Heisley Creek and Martin Ohm Creek, which drains 1766.9 acres and 1459.2 acres, respectively (Edgar, 2017). These sub watersheds share some similar characteristics, but with unique challenges making specific interest of research topics.

The Mentor Marsh watershed along the Lake Erie coastline is an under-appreciated and underutilized tourist area. From late 1950s, fresh water marsh was severely impacted. This was due to salt intrusion from upstream brine well fields and downstream salt fill over Blackbrook Creek. Later, these negative impacts start affecting the forest and others plant community in most part of the Lake Erie region (Fineran, 2003). The vegetative dynamics of Mentor Marsh was changed from an ash-elm-maple swamp forest to a current wetland dominated by *Phragmities austrailis (Cav.) Trin. Ex Steudel* (Poznik, 2003) resulting into the largest Phragmities marsh in Ohio.

Moreover, the impacts of elevated salinity in the marsh watershed led to the loss of the economic growth in the region due to substantial alteration or elimination of the habitat.

The introduction of elevated levels of salinity has created a condition that native plant species has been crowded out by other plant species. Due to the extreme level of salinity in marsh and swamp forest, the majority of trees in the marsh began to die. One consequence of this die off was the condition that led to the rapid establishment of Phragmites, resulting in the increased potential for fire.

Despite of being affected by the pollution and other physical challenges, it still attracts hikers, bird and nature loving people. This has significantly contributed to the local economy and will have a tremendous potential for future economic development via eco-tourism related activities if it can be restored. The economic return from eco-tourist activities, such as bird watching, has already been documented to have some impact to the local economy of this region (Xie, 2012).

Ungaged Watershed

A watershed is a hydrologic unit which produces discharge as an end product from a certain boundary. Finally, discharge is produced by the interaction of precipitation and the land surface through a common outlet. The aim of watershed modelling is to seek different results like flow analysis, sediment analysis, nutrient analysis, groundwater modelling and many more. In some watershed, the aim of watershed modelling may be to determine the maximum and minimum flow for water supply, while in the next is to analyze nutrients loading for the establishment of NPDES (National Pollutant Discharge Elimination System) permit. In this study flow was simulated using watershed model to predict salinity loading from upstream of Mentor Marsh watershed.

In order to conduct simulation study, observed streamflow data is crucial for appropriate model calibration and validation. However, streamflow data are not readily available from ungaged catchment. While there are several stream gauging stations (>60,000) installed worldwide (Blöschl, 2005), most watersheds do not have observed streamflow data as the United States and Geological Services (USGS) doesn't install gauging stations especially in the small tributaries. Since Mentor Marsh watershed is an example of ungaged watershed, a development of rating curve was necessary at ungaged Mentor Marsh watershed to obtain continuous stream flow data.

Field Study

A preliminary survey was conducted on October 2016 by a joint field survey team from Youngstown State University, City of Mentor and Lake County Soil and Water Conservation District to identify the appropriate location for the installation of the equipment. The most suitable locations for both tributaries, Blackbrook Creek and Marsh Creek, were identified. The water sampling site for Blackbrook creek was finalized on the upstream side of the culvert on Blackbrook road near pump station. Similarly, the water sampling site was identified on the downstream side of Marsh Creek Bridge on Lake Shore Boulevard.

Hydrologic Model Used

SWAT is one of the most advanced watershed models with a capacity to represent the complex watershed characteristics in terms of land use, soil, slope and digital elevation model. More importantly, SWAT model has been widely used for various ranges of watershed conditions, especially in the watershed with limited data; therefore, SWAT model has been selected for this study.

Instrument Used

Levelogger

The LTC Levelogger Junior was used in this study (Figure 1.2-a). It provides an inexpensive, helpful and convenient method which includes all sensors in one device to measure conductivity, level, and temperature of water. The device normally operates in the temperature range between - 20^{o}C to 80^{o}C and altitude range between -980 to 16400 ft. (300 to 5,000 m). It is capable to store the maximum of 16000 readings (Solinist, 2016).

Piezoresistive Silicon with Hastelloy sensor were used in this device to measure water level up to 30,100 ft. The level sensor of this probe works on the accuracy of ±0.1% FS. Similarly, Platinum Resistance Temperature Detector (RTD) was used to sense the water temperature. The temperature resolution and accuracy of this sensor are 0.1 ^{o}C and ± 0.1 ^{o}C respectively. Likewise, 4-Electrode Platinum conductivity sensor were inbuilt to measure conductivity ranges from 0 to 80,000 µS/cm. The accuracy of this sensor is ±2% reading or 20µS/cm and works on the resolution of 1µS.

Barologger

The Barologger model 3001 (Figure 1.2-b) was used in this study to monitor the fluctuations that occur in barometric pressure. It was used to barometrically compensate Levelogger readings specially water depth. It can compensate all the Leveloggers in 20 miles (30 km) radius with the change in elevation of 1000 ft. (300 m) (Solinist, 2016). The size of this device is 22mm × 154mm and weighs 179 gm. The device normally operates in the temperature range between -20^{o}C to 80^{o}C.

Two sensors were used in this probe to measure air temperature and atmospheric level. Piezoresistive Silicon in 316L stainless Steel measure the barometric level. The level sensor of this probe works on the accuracy of ±0.05% FS. Similarly, Platinum Resistance Temperature Detector (RTD) sense the water temperature. The temperature resolution and accuracy of this sensor were 0.003°C and ± 0.05°C respectively. It is capable to store the maximum of 40,000 of pressure and temperature readings.

Flow Probe

To develop the rating curve, the velocity of the stream is required to be measured. For this, a hand-held flow probe (FP111-FP211 Global Water Flow Probe) (Figure 1.2-c), a velocity measurement device was used for measuring water velocity in both Blackbrook and Marsh Creek. The Global water flow probe measures the instantaneous velocity to the nearest 0.33 ft/s (Global Water, 2016). The range of velocity measurement for this device was (0.33-20 ft/s).

Similarly, self levelling laser, level staff, engineering tape, chaining pins, C.G.I metal pipe, cable lock, metal rods were used as the supporting instruments and tools for instrument setup and discharge measurement.

Levelogger Calibration

The LTC Levelogger Junior conductivity calibration was performed by using a liquid solution, with a known conductivity value of 1,413 µS/cm, and the calibration data wizard in the Levelogger software. The data wizard was helpful to convert conductivity readings to salinity and are expressed in Practical Salinity Units (PSU). The sensor was calibrated at room temperature (68 degrees Fahrenheit or 25 degrees centigrade) for the reliability of the measured conductivity before installation. In general, the calibration of the LTC Levelogger instrument was performed before the instrument setup and at least twice a year at the beginning of the seasons for better performance (Figure 1.3).

Instrument Setup

The monitoring sites were established at the Black Brook Creek (at 41º 43’ 22.85’’N, 81 º 17’ 28.1’’ W) and Marsh Creek (at 41º43’12.33’’ N, 81º20’’19.9’’W) with in the watershed (Figure 1.4). Automated LTC Levelogger junior and Barologger devices were installed at the water-monitoring location on October 2016. The first set of instruments (Levelogger and Barologger) were established at first water sampling site on the upstream side of the culvert on Blackbrook road near pump station (Figure 1.5). Similarly, the second Levelogger instrument was established at second water sampling site on the downstream side of Marsh Creek Bridge on Lake Shore Boulevard (Figure 1.6). These stations were selected in such a way that the site is accessible for data download and stream cross-section is almost straight with narrow gorge for measurement of river cross-sections.

Measurement of Cross-Section, Stage and Velocity

Levelogger device continuously measured the water stage throughout the year in every hour interval at both Blackbrook and Marsh Creek gauging station. The site for cross section measurement for Blackbrook (Figure 1.7) and Marsh Creek (Figure 1.8) were established at the instrument locations. Flow velocity and water stage were measured using a hand-held flow probe and level staff respectively in both Creek. The Creek cross-section were measured with the help of levelling laser and level staff in both creeks. The cross-section, stage and velocity were measured at least twice a month by field measurement. The flow depth and velocity recorded in the field observation were converted into streamflow for the development of rating curve.

Development of Rating Curve

USGS develops its rating curve at its every gauging station to convert the water stage (ft) into volume of water (ft^3/s). It is developed by measuring frequent discharge measurements at monitoring stations. USGS regularly measures the stage and discharge measurements to ensure various ranges of stage and discharge are measured correctly in order to represent high and low flows well in the rating curve.

The rating curve was developed at Blackbrook Creek water monitoring station at the same place on the upstream side of culvert near the city of Painesville (Figure 1.9). The rating curve was developed with 40 observed discharge and its corresponding stage datasets. In fact, USGS calculates flow at gauging stations throughout the United States using the same approach of stage discharge relationship. The flow depth recorded in the stream were converted into streamflow after developing the stage discharge (rating) curve. The developed rating curve was utilized to predict the water flow in the Blackbrook Creek.

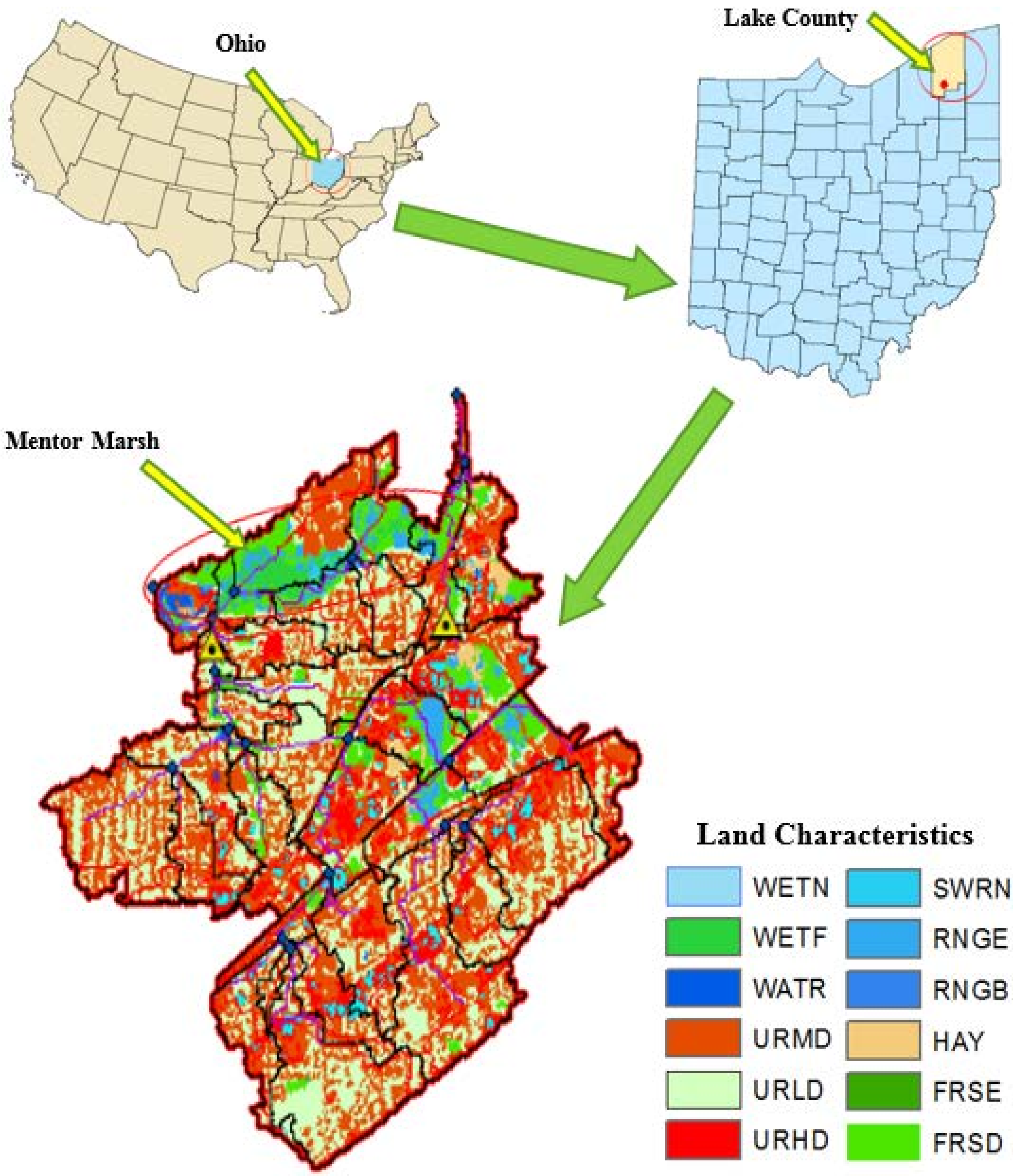


Figure 1-1: Study area of the Mentor Marsh watershed consisting sub-basins and water monitoring stations

(a) (b) (c)

Figure 1-2: Levelogger (a), Barologger (b) and Flow Probe (c)

Figure 1-3: Calibration of Levelogger before instrument installation

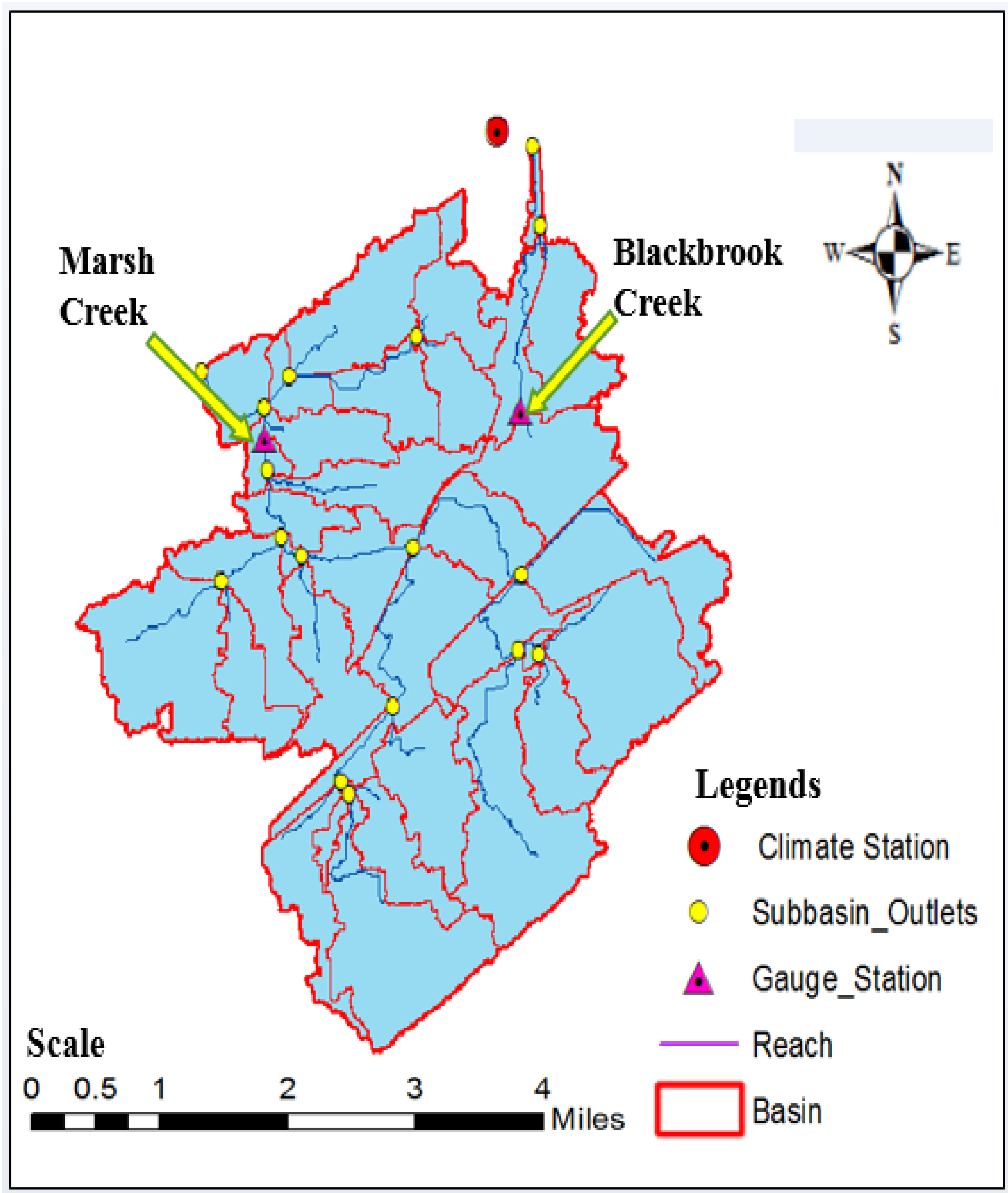


Figure 1-4: Location of gauging station at Blackbrook Creek and Marsh Creek

Figure 1-5: Levelogger instrument setup on the upstream side of culvert and Barologger at pump station (top left corner) on Blackbrook road

Figure 1-6: Levelogger instrument setup on the downstream side of Marsh Creek Bridge on Lake Shore Boulevard

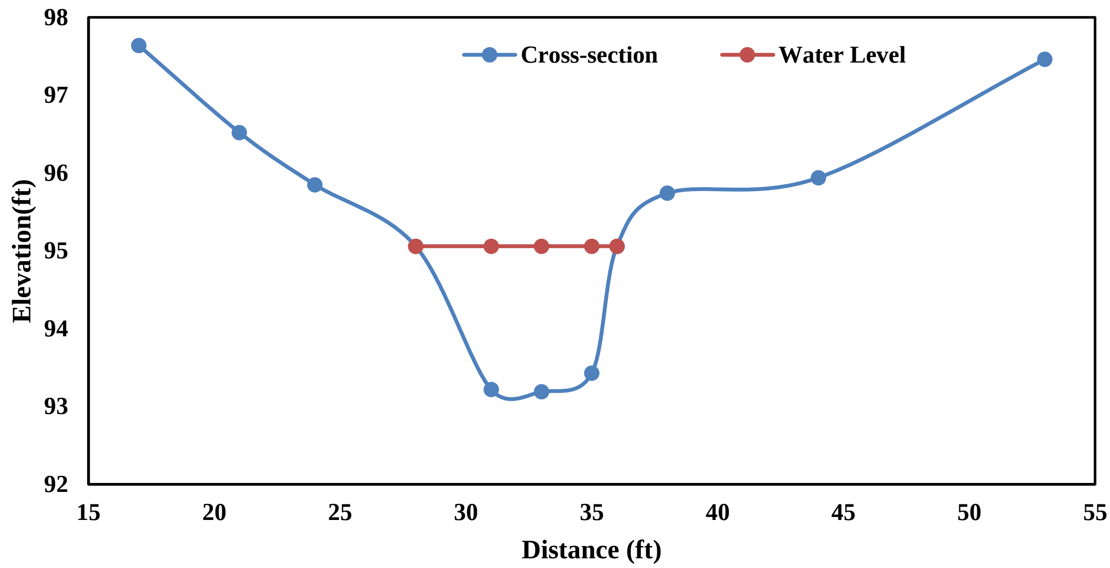


Figure 1-7: Blackbrook Creek cross-section at flow monitoring site

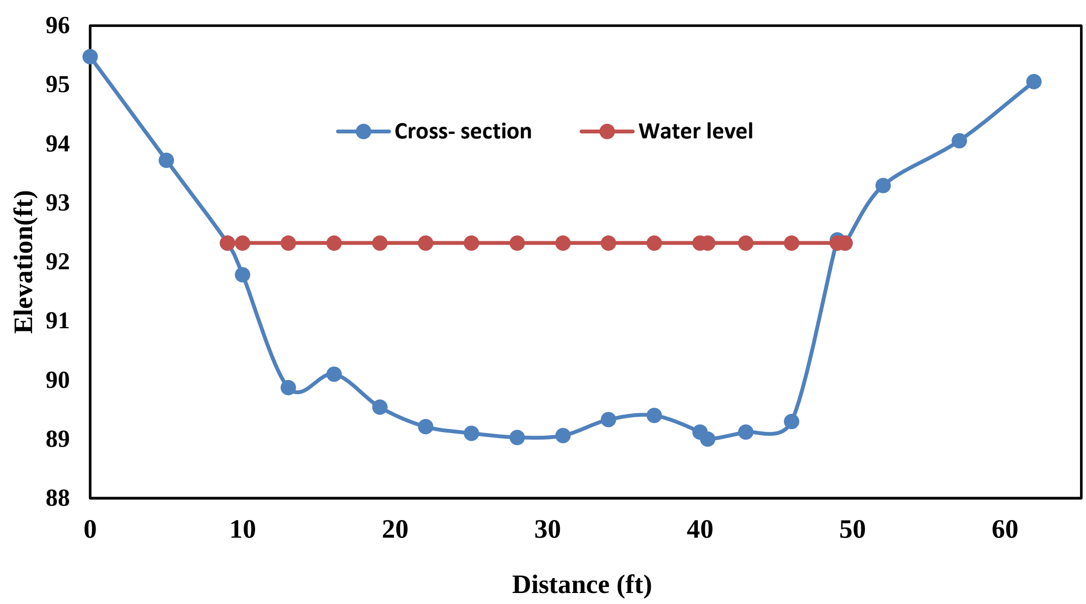


Figure 1-8: Marsh Creek cross-section at flow monitoring site

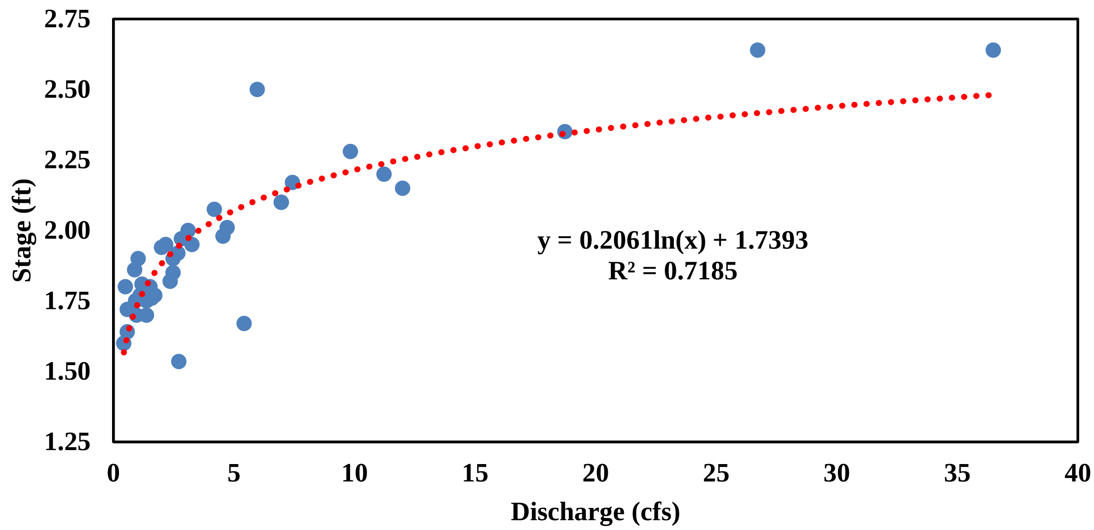


Figure 1-9: Development of Stage Discharge (rating) curve at Blackbrook Creek monitoring site

Chapter 2

Hydrologic Modelling Using SWAT in Small Ungaged Catchment for Salinity Prediction

Introduction

The collection and deposition of soluble salts from different point and nonpoint sources are the major factors for wetlands pollution (Herbert et al., 2015; Fujioka, 2001; McElroy,1976). Increase in salinity level in wetlands is a widespread environmental problem in many parts of the world in terms of profound consequences in wetland plants and aquatic habitats (Herbert et al.,2015; Williams, 199). Even though the wetlands are protected by the environmental acts issued by the regulating agencies, the possibility of disturbance by the accidental spillage of toxic materials into water sources is always possible (Broome et al., 1988). The different sources of salt pollution on wetlands are from agricultural drainage (Khalil et al., 1967), construction of highway and road salt application (Novotny et al., 2008), leakage from offshore petroleum pipelines (Broome et al., 1988), port construction (Muniz et al., 2005), power generation facilities (Carlson et al., 1993), and urbanization and industrialization. Moreover, many other factors including rise in groundwater table (van der Kamp and Hayashi, 2009), evaporation, acid rain (Baker, 1992), sediment type, and water logging also have an influence on wetlands (Huckle et al., 2000).

As the standing water on the marshland does not flush easily, the deposited salts remain for a longer period of time, which has a potential to detrimental impact on wetland ecosystem and landscape dynamics (Fineran, 2003; Herbert et al., 2015). These impacts play a crucial role on degradation of biodiversity, change in their natural habitat, functional integrity and destroy delicate plant populations (Lövei, 1999; Mack et al, 2000.; Fineran, 2003; Pezeshki et al,1990.; Krauss et al.,2000). Moreover, these problems replace the native plant species having low salt tolerance ability with high salt tolerant plants such as *Phragmites australis* (Cav.) Trin ex Steud (common reed) (Mauchamp et al., 2001).

Phragmites is a common example of dominant and nuisance species in North American wetland plant communities in the past century (Cronk and Fuller, 1995; Chambers et al. 1998). Several researchers in the past have conducted to comprehend invasion of phragmites in North America (Lissner and Schierup, 1997; Chambers, 1998; Meyerson, et al., 2000; Galatowitsch et al., 1999; Vasquez et al., 2006) and throughout the United States (Roman et al., 1984; Mack et al., 1994). It was found that salinity is the major factor for increasing population of phragmites in both tidal and inland marshes (Meyerson et al., 2000; Chambers et al., 1998). The maximum level of salt tolerance by these species was reported in the range between 12 ppt to 40 ppt (Finlayson et al., 1983). They grow about two to four meters in height and stands with dead culms and dry leaves in winter (Poznik, 2003). These dry Phragmites led to several major fire incidents in marsh (Thompson and Shay, 1985). Therefore, controlling phragmities has turned into a priority concern for wetland administrators (Marks et al., 1994). In this context, identifying the hot spots of salinity loading and its concentration with respect to flow using watershed modeling is essential to investigate salinity intrusion.

Many researches in the past have been conducted to comprehend salinity modelling by using various empirical models (Wang et al., 1992; DeSilet et al., 1992), statistical models (Gibson and Najjar; Prairie et al., 2005), hydrologic models (Gibbs et al., 2011; Michot et al., 2015; Mittelstet et al., 2015) and hydrodynamic models (Mohd et al., 2015; Meselhe and Noshi, 2001). Those modeling studies were typically conducted to correlate the streamflow with salinity loadings. For example, the study conducted by Dawes et al., 2004, in the unregulated catchment showed that the salt load from the small upland catchment was linearly related to the streamflow rate. The study conducted by various scientists (Mittelstet et al., 2015; Somura et al., 2009; Gikas et al., 2009; Piman et al., 2013) in Japan, Greece and Southeast Asia suggested that model predicted flow from SWAT with the combination of other salinity modelling tools or regression equation were proven the best tool and methods to predict salinity loading. Similarly, the study conducted by Gassman and Yingkuan (2015) and Tomas et al. (2014) supported the fact that simulated flow from SWAT model was useful for salinity modelling.

Majority of these studies did not directly simulate the salinity loadings, rather simulated the flow and correlated the model generated flow with salinity loadings. Even though watershed model does not simulate salinity, the simulated flow from the model can be utilized to develop a regression equation between streamflow with salinity, which is potentially useful to predict salinity loading. Nevertheless, simulation of the flow in an ungauged catchment is crucial (Deckers, 2006) due to the lack of observed data. Prediction of flow at ungauged catchment is relatively more complicated as compared to gauged catchment leading to the higher degree of uncertainty (Sivapalan et al., 2003). While there are several stream gauging stations (> 60,000) installed worldwide, most of the catchments around the world are ungauged. The United States and Geological Services (USGS) also doesn’t have gauging stations to record continuous flow data in all streams. Therefore, the development of rating curve using the stage data recorded from Levelogger and occasional recording of streamflow could be easy, viable and more economical option to record the streamflow in an ungauged catchment.

In this study, a widely used watershed model, Soil and Water Assessment Tool (SWAT), has been developed using observed streamflow through the stage rating curve established in a section based on the continuously measured stage in the levellogger and occasional flow rate measurement in the site.

SWAT Model

The Soil and Water Assessment Tool (SWAT) is a semi-distributed hydrologic model jointly developed by USDA-ARS and Agricultural Experiment Station in Temple, Texas in the early 1990s (Arnold et al., 1998). This model has a capacity to address the complexity of the watershed in terms of land use, soil and slope (Arnold et al., 2001). SWAT can simulate various components water flow, nutrient cycling, crop growth and sediment transport as physical process (Jain et al., 2010).

SWAT was originally developed to predict the long-term impact of watershed management in terms of hydrologic and water quality response of large watershed (Moriasi et al., 2007). The hydrologic modeling is conducted by using either Green or Ampt or SCS curve number method (Arnold et al., 1988). The Green and Ampt equation is used for hourly flow estimation whereas an empirical SCS curve number (CN) method is used for daily flow computation.

A watershed is delineated into sub-watersheds including land catchments, flow directions and stream network inland phase modeling. These sub-watersheds are further divided into hydrologic response units (HRUs) which are further subdivided into homogeneous land use, soil type and slopes also called management characteristics. Finally, loadings from each sub-basin are connected together with stream networks and routed towards outlet through different channels and reservoirs in their routing phase (Arnold et al., 2001) .

Material and Methods

The detail methodology is explained in chapter 1 in detail.

SWAT Model Inputs

SWAT was used to model entire hydrologic process, which included the evapotranspiration, shallow infiltration, deep aquifers percolation and lateral flow study. Since it can represent the complexity of the watershed using various model inputs, Digital elevation model (DEM), land use, slope length, soil type, stream network, temperature, precipitation and reservoir were utilized for SWAT modelling. ArcGIS interface was used to extract necessary information from these different available datasets to conduct further analysis.

In order to accurately represent the topography of the sites, high resolution DEM of 3m were downloaded from the USGS National Elevation Dataset (NED) in raster format, which contain topographic information such as stream networks, slope length and slope gradient. These DEM datasets were used to delineate the watershed into 35 sub-basins by using SWAT automatic watershed delineation. Similarly, the most recently available land use dataset with a spatial resolution of 30 m was used from the USDA. The distribution of land use in the watershed is presented in Table 2.1. Soil plays a crucial role while modelling different hydrological processes. Therefore, high resolution, Soil Survey Geographic (SSURGO) data sets were downloaded from USDA. Since the catchment size is relatively small, the detailed soil datasets such as SSURGO was selected, which high resolution has compared to the State Soil Geographic (STATSGO) data. Since runoff generated from the watersheds depends on the actual hydrologic conditions of soil, land cover and topographic conditions of the watershed, appropriate threshold of land use, soil and slope should be provided in the model in order to better represent the different flow predictions in the watershed. Therefore, the threshold value for land use (5%), soils (10%) and slope (15%) were subsequently used to generate 346 hydrological response units (HRUs).

The climate data including precipitation, maximum and minimum temperature were downloaded from National Climatic Data Center (NCDC) website for Painesville station (USC00336389). However, the remaining climatic datasets such as solar radiation, wind speed, and relative humidity were simulated using the weather generator function in the SWAT model. Daily and monthly streamflow data needed for model calibration and validation were generated from developed rating curve and installed Levelogger instrument at Blackbrook Creek.

Model Setup, Calibration, and Validation

The SWAT model was set up and run from 2012 to 2018 in monthly time steps using a 4-year warm up period (2012-2015). Since hydrologic modeling is associated with certain degree of uncertainties, the model needs to be properly calibrated and validated before conducting any analysis (Engel et. al., 2007). Therefore, the model was calibrated by using continuous observed streamflow record derived from rating curve established with in the watershed at Blackbrook Creek. The streamflow records were obtained for a 17-month period from November 2016 to Mar 2018 at Blackbrook Creek station. For the calibration, multiple parameters were adjusted manually by an iterative process to produce the best fit result between the observed and simulated data. For this, various sets of model parameters were selected by observing watershed characteristics (Table 2.2).

The model was calibrated in a monthly time scale from November 2016 to August 2017. These model parameters were then independently validated using observed streamflow data from September2017 to March 2018 with respect to coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE) and percent of bias (PBIAS).

Results and Discussions

SWAT Model Performance

The model performance was evaluated with the help of different statistical indicators based on daily and monthly time scale at Blackbrook Creek station. The various model parameters selected for the calibration of the model are reported in Table 2.2. The model was performing well in both calibration and validation period with reasonable accuracy and within the recommended range (NSE > 0.50, PBIAS ±25% and RSR ≤ 0.70) given by (Moriasi et al., 2007). In this study, the performance indicators R^2, NSE, RSR, and PBIAS for monthly flows at the outlet were 0.87, 0.86, 0.37 and -2.9% respectively in calibration phase. Similarly, for the validation phase, the value for different model indicators were 0.87, 0.78, 0.35 and -13% respectively. Furthermore, the performance of the model was evaluated using graphical plotting of observed and simulated flow. The Average monthly-observed vs simulated flow during the calibration period (Nov-2016 to Aug-2017) and the validation period (Sep-2017 to Mar- 2018) at the Blackbrook outlet was graphically plotted in (Figure 2.1).

SWAT commonly underestimates the daily and monthly simulated peak flows (Bieger et al., 2014; Santhi et al., 2014). Similarly, the developed model also failed to capture few simulated low and peak flows during calibration and validation phase. This could be due to the differences between SWAT simulated discharge and the manually observed discharge obtained from rating curve. Similarly, there could be potential errors in input data such as weather, land use, soil, observed flow etc. (Santhi et al., 2001).

Observed Variability of Flow and Salinity Level in Marsh

This study was conducted from late 2016 to early 2018 to predict water salinity level with respect to flow. Similarly, the salinity data were also recorded and separately analyzed in hourly, daily, monthly, and seasonal scale throughout the study period. The study was primarily focused to quantify the salinity level from upper part of Mentor Marsh watershed. At the downstream of watershed, the Blackbrook creek was flowing below the salt fills through concrete culvert (Figure 2.2) before being rerouted in 1988 (Fineran, 2003).

Figure 2.3 shows the comparison between monthly observed salinity level and streamflow discharge in both Blackbrook and Marsh Creek. The analysis shows the trend of increase in salinity (mg/L) with decrease in discharge (cfs) and vice versa. However, positive correlation was detected during the months of winter season.

The hourly, daily and monthly salinity records are essential to analyze temporal and spatial variability of salinity level within the watershed. Figure 2.4 depicts the comparison of hourly salinity level in Marsh and Blackbrook Creek. It captured some higher salinity value at the particular moment of the day. This is not surprising to experience such an abrupt variation in salinity especially in hourly scale because the leakage of brine well fields was still observed in the recent field visits. The water salinity in Blackbrook fluctuated between 234 mg/L to 3668 mg/L. However, water salinity in Marsh Creek varied between 77 mg/L to 2940 mg/L.

Similarly, Figure 2.5 shows the comparison of daily salinity level in Marsh Creek and Blackbrook Creek. The variability of water salinity in daily scale was relatively less compared to hourly scale. The daily salinity in Blackbrook ranged from 275 mg/L to 2837 mg/L. The lowest salinity was observed in the month of November, whereas the highest was recorded in the month of February. Likewise, the water salinity in Marsh Creek oscillated between 111 mg/L to 2585 mg/L with the lowest record in November and highest in the month of January. The graphical analysis suggested that the salinity in Blackbrook and Marsh creek followed the consistent pattern except during winter season. However, this trend changed by the second half of April due to the back-water effects from Lake Erie and continued until the beginning of early May. Backwater effect was not anticipated on the monitoring site based on the of several years records of Lake Erie level. Similarly, there was a large fluctuations of salinity level in Marsh Creek and Black Brook Creek from early December 2017 to the second half of February 2018. During this period, Marsh Creek continuously exceeded the salinity level than that of Blackbrook Creek. This trend reversed from the second week of January 2018 and continued up to the second half of February 2018.

The monthly salinity level in Marsh Creek and Blackbrook Creek is presented in Figure 2.6. The water salinity at Blackbrook and Marsh Creek varied between 419 mg/L to 1538.43 mg/L and 275.57 mg/L 2017 to1398.26 mg/L, respectively. The lowest salinity level was captured in the month of November and the highest salinity level was captured in the month of February. It is interesting to note that higher salinity level was detected consecutively from December to March as compared to the other months of a year. The higher concentration of salinity during this period might be due to the excessive application of road salt for deicing purpose. Similarly, seasonal salinity variation is shown in Figure 2.7. The graph shows winter and spring seasons captured higher salinity level in both year

2017 and 2018. While the salinity level was higher in both creeks on other seasons as well, the significant variability of salinity level was not detected.

Furthermore, the observed salinity concentration and flow were computed and changed into salinity loading in both Creeks. The instrument was disturbed at the monitoring site in the month of February to early March in 2017. Therefore, actual salinity loading was not computed. Figure 2.8 shows the monthly observed salinity loading in Blackbrook and Marsh Creek. The analysis shows both Creeks had higher monthly salinity loading as compared to fresh water Creeks indicating that Marsh Creeks received significant salinity loading in the months of winter and spring seasons. Similarly, the Blackbrook Creek received significant salinity loading in the months of spring season and some months of fall and winter seasons. Regardless, Marsh Creek contributed more salinity loading compared to Blackbrook in downstream Marsh land. Figure 2.9 shows the box plot of observed median salinity loading in Marsh creek and Blackbrook creek throughout the study period. The monthly median salinity loadings in Blackbrook and Marsh Creek were 55 ton and 329 ton, respectively. The result showed that Marsh Creek contributed 10 times higher salinity loading compared to Blackbrook Creek.

Historical Salinity Loading

After calibration and validation, the SWAT model was re- run in the historical time period from 2000 to 2016 using climate data from Painesville station (USC00336389) to generate historical discharge. The correlation equation between salinity loading and discharge in daily (R^2 = 0.71) and monthly (R^2 = 0.82) scale was established in Blackbrook Creek (Figure 2.10). Similarly, the daily and monthly R^2 of streamflow with salinity in Marsh Creek was 0.86 and 0.76, respectively (Figure 2.11). The developed correlation equation and model predicted flow was utilized to compute the salinity loading in the historical time period.

The monthly simulated salinity loadings averaged for each month, during the historical period of 2000 to 2016, shows that Marsh creek had nearly 10 times higher salinity loading than that of Blackbrook creek (Figure 2.12). Similarly, seasonal salinity loading into the Marsh creek for historical period, computed average for each season from 2000 to 2016, was found higher than that of Blackbrook creek, which was consistent with our observed data (Figure 2.13). It shows that Marsh creek had higher seasonal median salinity loading in spring season (3792 ton), which successively decreased in summer (1236 ton) and fall (1103 ton) and increased in winter (2286 ton). This is not surprising because the flow was relatively higher in winter and spring season and the salinity loadings were primarily generated using the regression equations established between flow and salinity. Similarly, Blackbrook creek also had higher seasonal median salinity loading in spring season (246 ton) and successively decreased in summer (118 ton) and fall (110 ton) with a slight increase in winter season (161 ton). Likewise, Figure 2.14 shows that both creek received higher salinity loading in year 2008 and 2011, and the smaller salinity loadings in year 2000 and 2001 indicating the consistent trend of loadings and the degree of variability from year to year.

Figure 2.15 shows the annual salinity loading in Blackbrook and Marsh creek from (2000-2016). The box plot suggests that the Marsh creek contributed more salinity loading compared to Blackbrook Creek. The annual median salinity loading shows that Blackbrook Creek and Marsh Creek transported 620 ton and 8334 ton of salt, respectively towards marsh. The higher salinity loading from Marsh could be mainly due to the size of catchment which contributes more road salt from relatively large catchment size as compared to Blackbrook Creek. Road salt has been widely practiced as a deicing agent at pavement surface from departments of highway since the early 1960's (Demers and Sage, 1990). According to the study done by Murray and Ernst (1976), approximately 8.2 x 10^6 tons of salt are applied every year in the country's road and out of the which, 70% used in Northeast (Hanes et al., 1970).

Conclusion

There is an increasing need of in-depth salinity study in Mentor Marsh watershed to protect first natural preserve of Ohio. Therefore, this study was aimed to investigate the impacts of long term variation of salinity loading with respect to flow from two tributaries, Blackbrook and Marsh Creek. For this purpose, we developed a watershed model to simulate daily Creek flow from Mentor Marsh watershed using SWAT model. Although some modeling studies were conducted across the world especially to correlate the salinity loading with simulated flow, correlating salinity with model simulated flow to predict the salinity loading particularly in an ungaged catchment such as Mentor Marsh was a great challenge. More importantly, none of the prior research have been performed using a watershed model to investigate salinity level in Mentor Marsh. Therefore, two monitoring stations were established in Blackbrook and Marsh Creek for real time data recordings of stage, stream temperature and electrical conductivity. The measured conductivity was converted into salinity using Solinist Levelogger data wizard. Since the watershed model do not directly simulate the salinity level, we utilized the observed streamflow data to calibrate and validate the SWAT model and the correlation equation between flow and salinity was established to predict the salinity loading.

The analysis suggested that the salinity level captured in both Creek was consistently higher with most of the data values within oligosaline i.e. (500 to 5000 mg/L) category. It also indicated that Blackbrook Creek continued to experience higher level of salinity (mg/l) than that of Marsh Creek. Initially, we expected the lower salinity level in Blackbrook Creek as the monitoring station was located in the upstream from the salt fill and the salt fill tailings was not included. From the field investigation it is was clear to us that old brine fields which were closed decades ago are still leaking continuously. Another important finding of this research study was the variation of salinity level during winter and early spring season in both Creeks. Marsh Creek salinity level was observed higher than that of Blackbrook Creek for certain interval of time in winter season and kept fluctuating. However, rest of the year salinity level was found higher in Blackbrook compared to Marsh Creek.

The historical daily and monthly salinity loading also showed that Marsh creek had higher salinity loading than that of Blackbrook Creek. Similarly, both Creeks had higher median salinity loading in spring and winter season. The result showed that both Creek received higher salinity loading in wet year 2008 and 2011.

The continuous deposited salt increased the growth and development of phragmites in the downstream marsh land. As a matter of fact, it led to the rapid establishment of phragmites and increase the potential for fire hazard for community near the marsh. In order to avoid the Marsh fire, the sources of salt pollution for phragmites growth must be controlled. Therefore, an immediate action should be taken to rectify the old brine fields before rapid urbanization occurs. We also recommend ODOT to come up an alternative approach for deicing the salt or to use the limited amount around the area during winter season. Even though the complete removal of phragmites from Marsh land does not seem to be feasible, we recommend the managers, policymakers and different conservation agencies to come up with long-term research for further analyses to understand the salinity sources and loading pattern in the downstream Marsh.

Activities and Timeline

- We met various stakeholders from the City of Mentor, LCSWCD, Cleveland Museum of Natural History and OEPA (agency advisor) and collected useful information from them (Jan16-Spring 2018)
- Data collection (Nov 16-till now)
- SWAT model calibration and validation (completed by Dec 2017)
- Salinity loading analysis (Spring 2018)
- Report writing (Spring 2018-Fall 2018)
- Result Dissemination: Dec 2017-till now/future
    - Presentation in conference (ASCE/EWRI, June 3-7, Minneapolis, MN)
    - Presentation in QUEST conference (April 3, YSU, 2018)
    - Presentation in ORBCRE conference (schedule for October 17-19, 2018)

Deliverables

A model has been developed to predict streamflow and salinity under various climate and seasons.

1) Salinity contribution from the two tributaries has been reported.
2) Publications: a) A manuscript has been prepared and it will be submitted to the peer review journal soon ("Temporal and spatial variability of streamflow

and salinity level in the ungaged watershed, Mentor Marsh for the ecological benefit.")

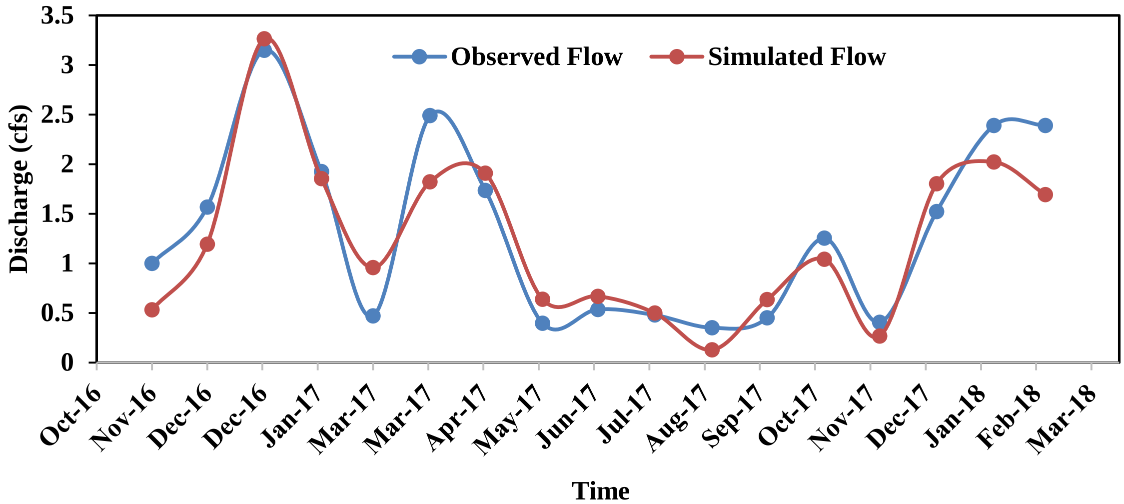


Figure 2-1: Calibrated and validated streamflow at the watershed outlet at Blackbrook Creek

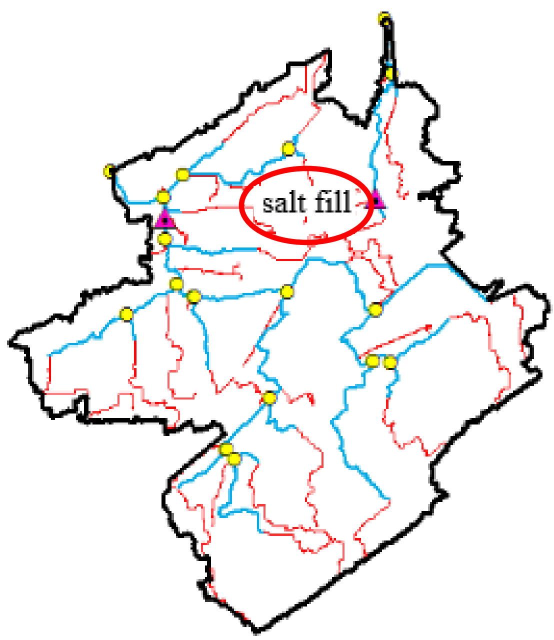
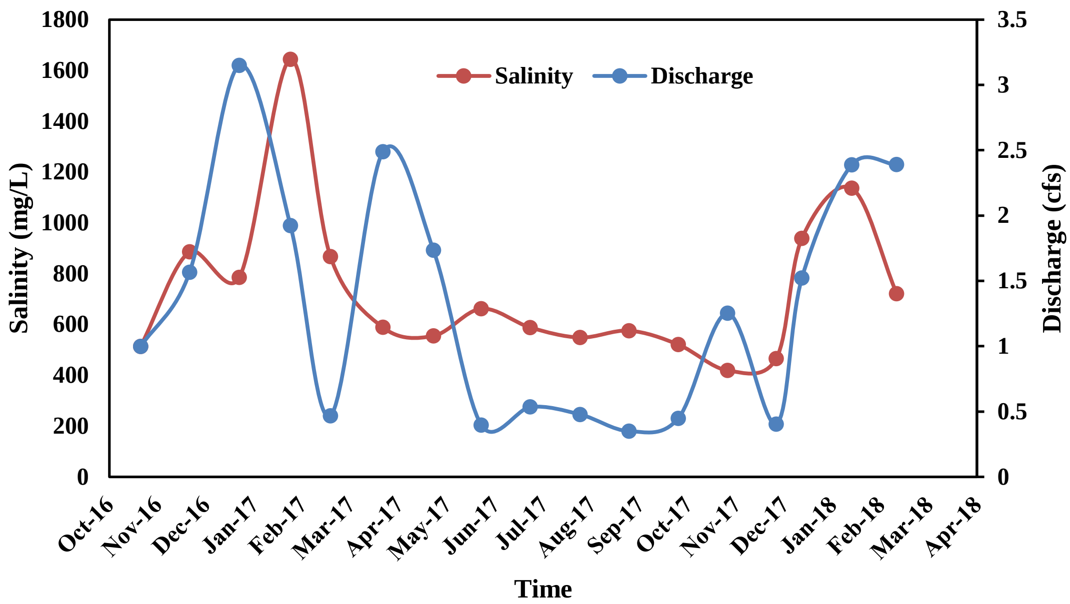
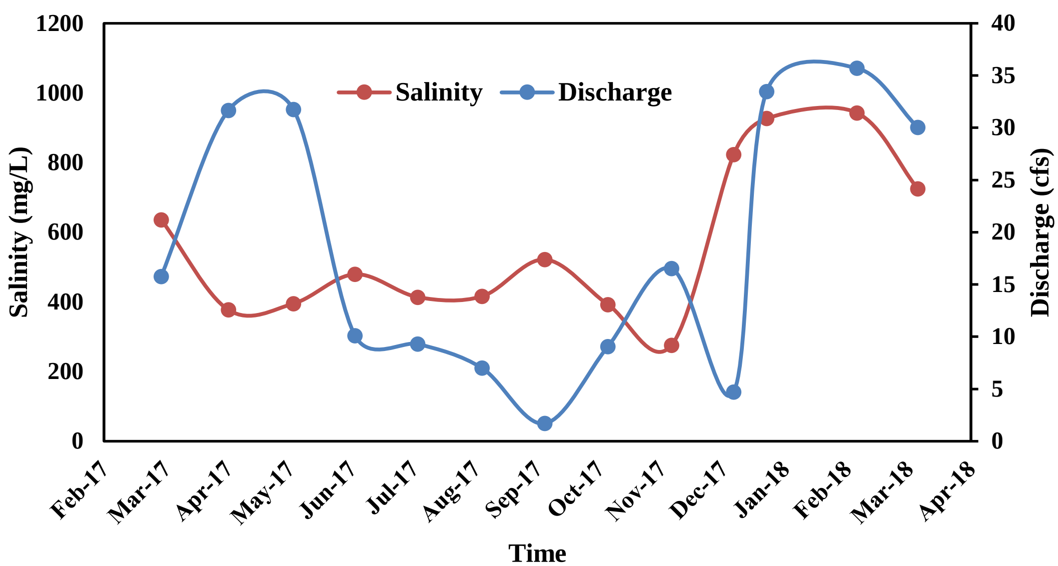


Figure 2-2: Saltfill site over Blackbrook Creek before rerouted



(a)



(b)

Figure 2-3: Monthly salinity and Discharge comparison at Blackbrook Creek (a) and Marsh Creek (b)

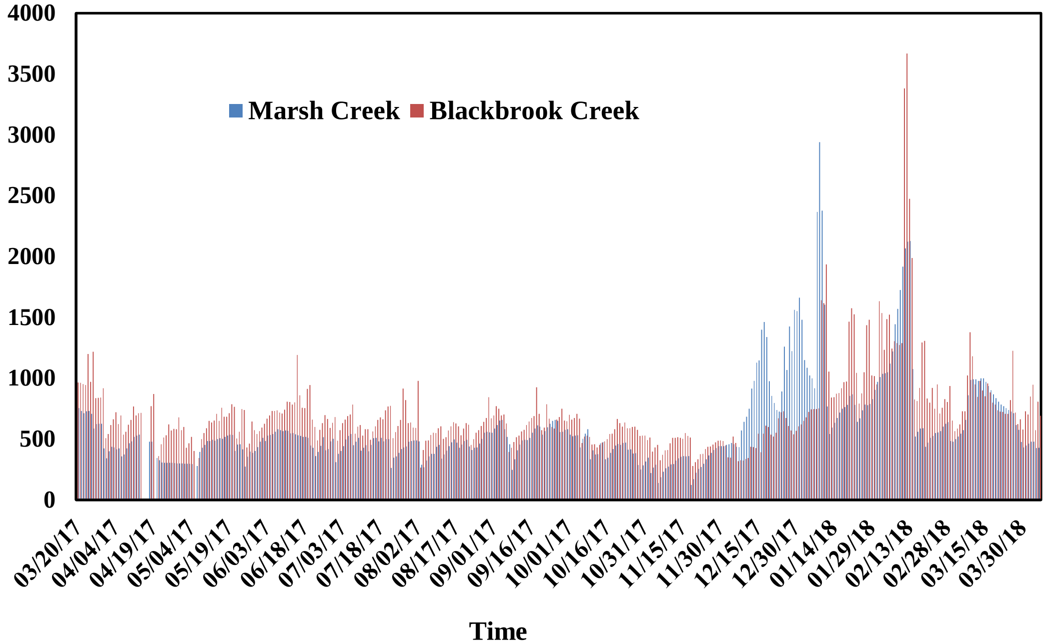


Figure 2-4: Hourly salinity comparison at Blackbrook Creek and Marsh Creek

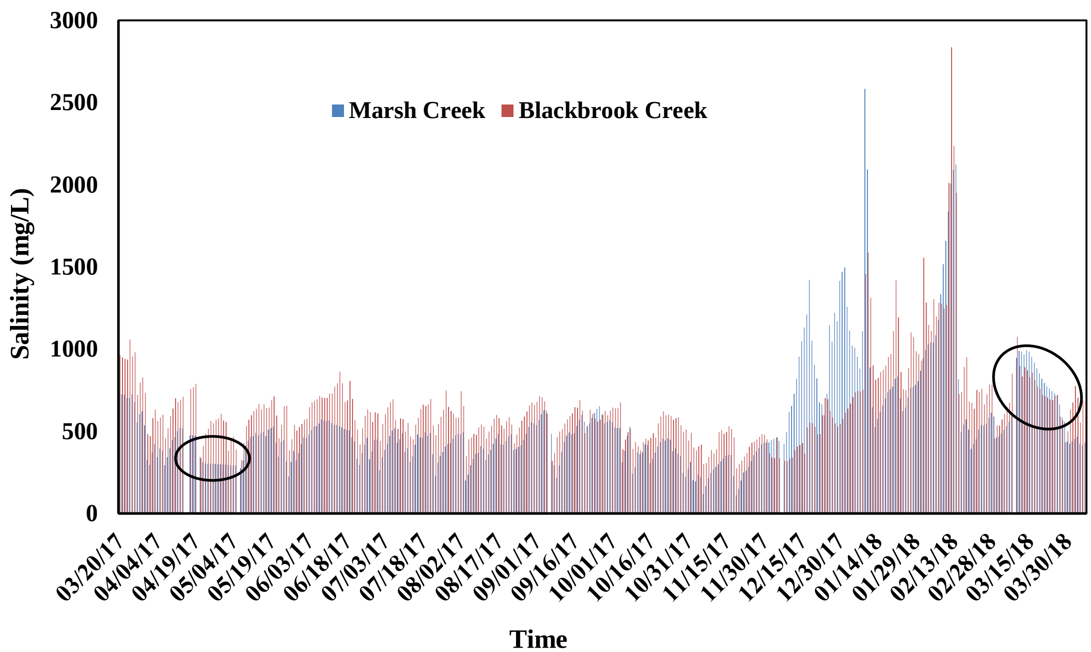


Figure 2-5: Daily salinity comparison at Blackbrook Creek and Marsh Creek

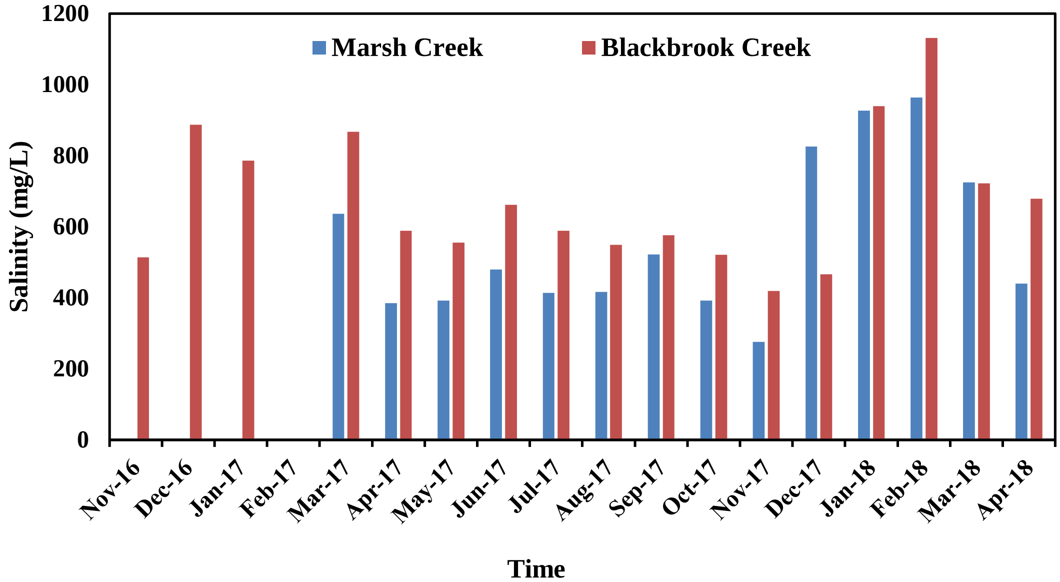


Figure 2-6: Monthly salinity comparison at Blackbrook Creek and Marsh Creek

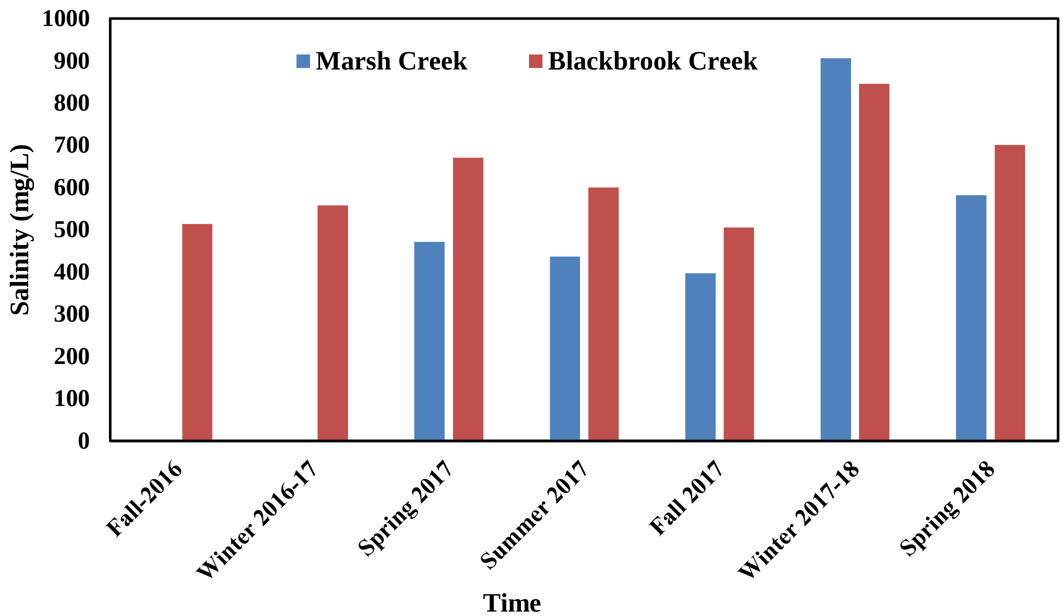
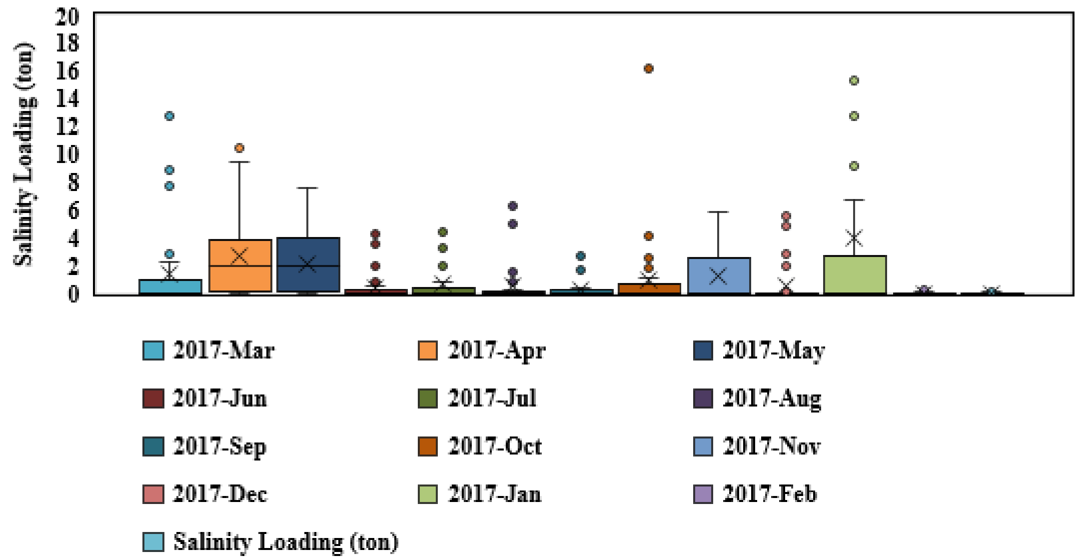
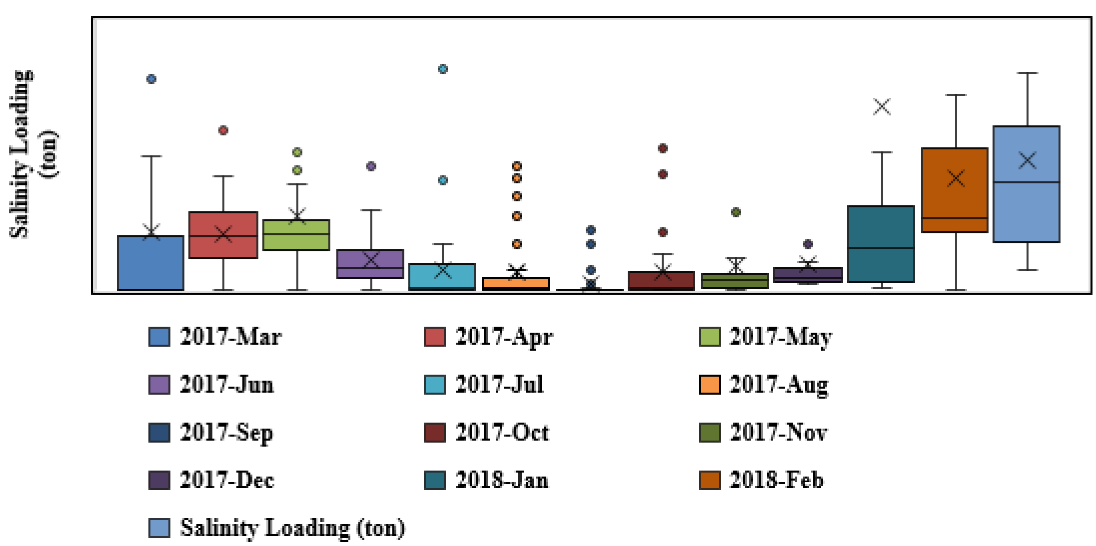


Figure 2-7: Seasonal salinity comparison at Blackbrook Creek and Marsh Creek

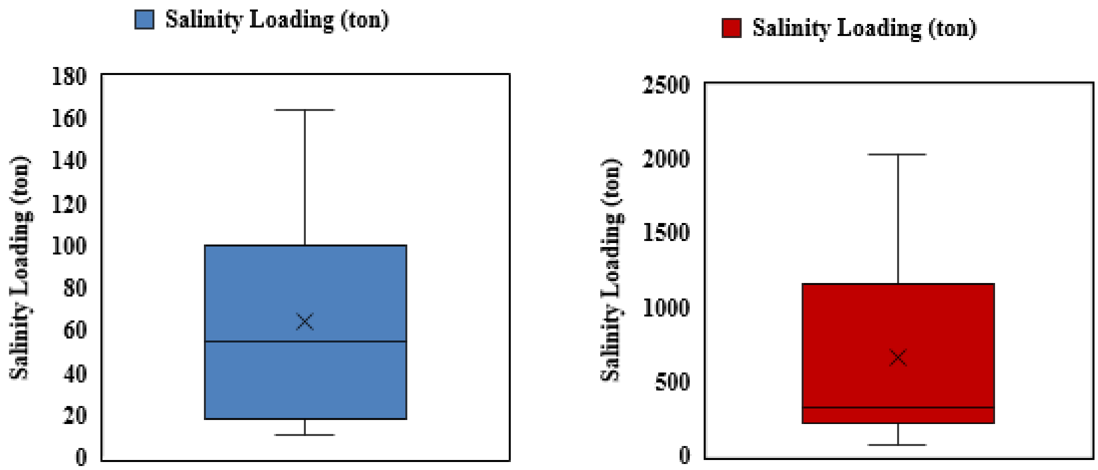


(a)



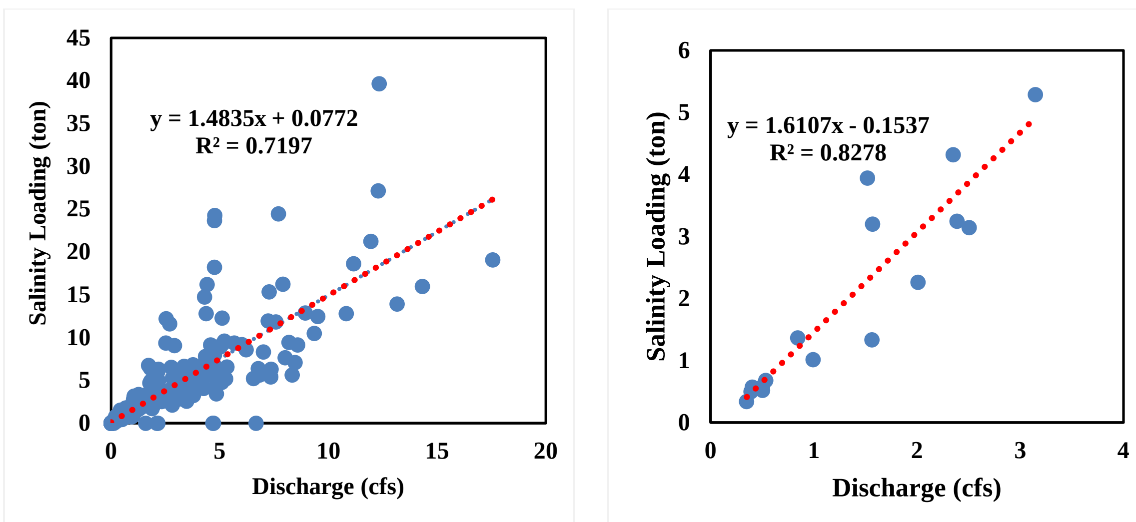
(b)

Figure 2-8: Observed monthly salinity loading at Blackbrook Creek (a) and Marsh Creek (b)



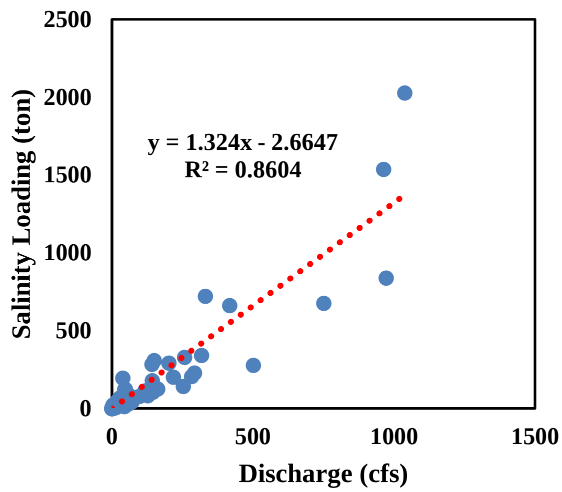
(a) (b)

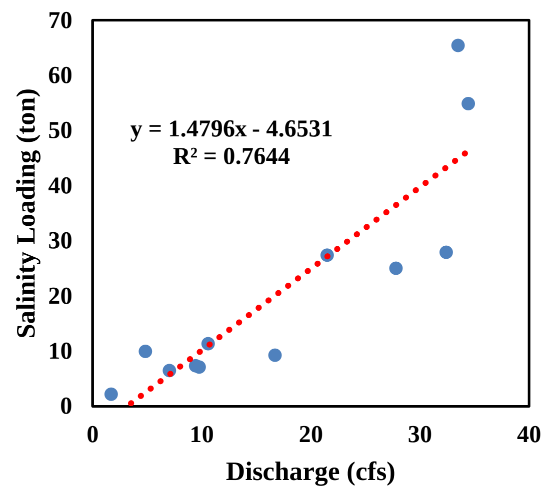
Figure 2-9: Total observed monthly salinity loading at Blackbrook Creek (a) and Marsh Creek (b)



(a) (b)

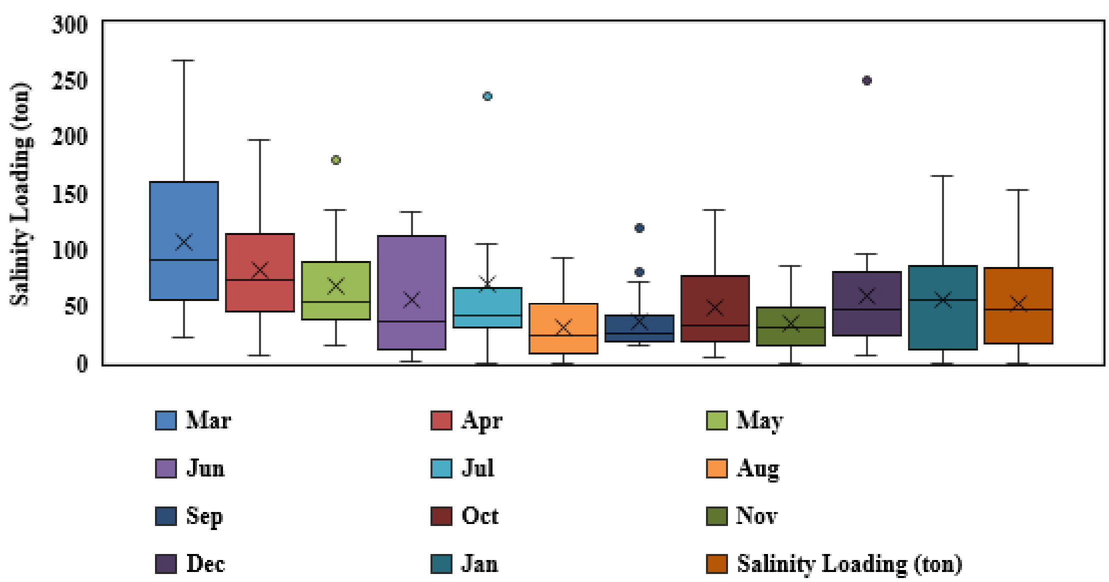
Figure 2-10: Correlation between salinity loading versus streamflow at Blackbrook Creek on Daily Scale (a) and Monthly Scale (b)



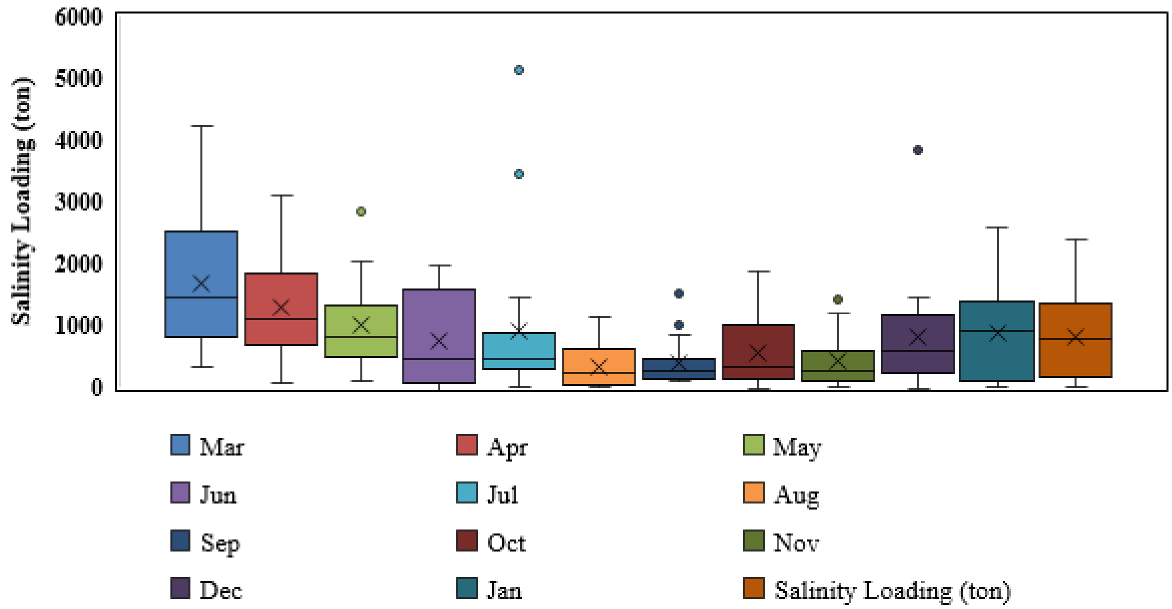


(a) (b)

Figure 2-11: Correlation between salinity loading versus streamflow at Marsh Creek on Daily Scale (a) and Monthly Scale (b)

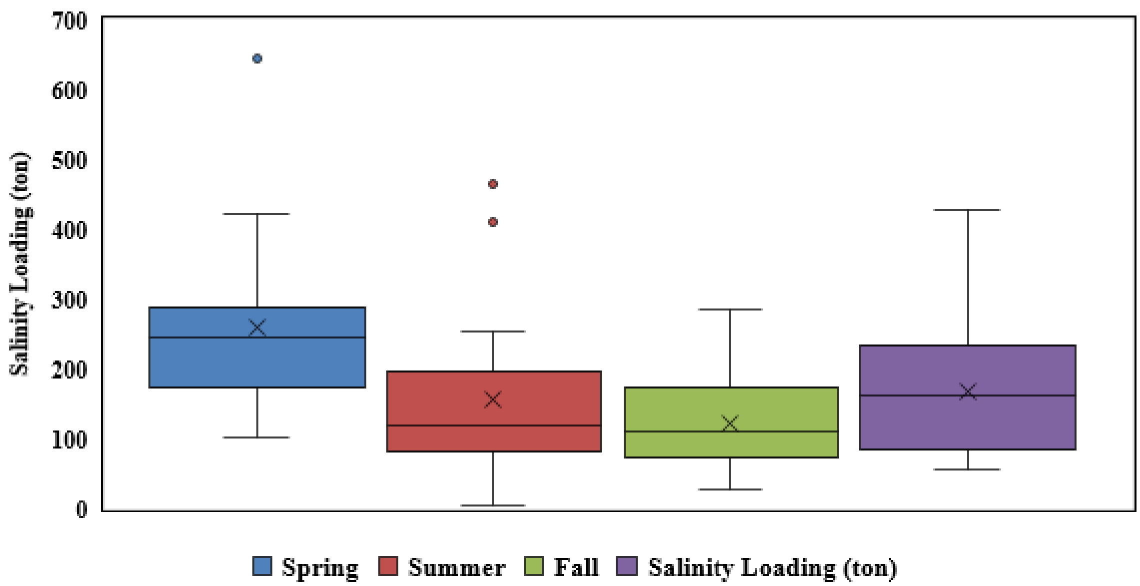


(a)

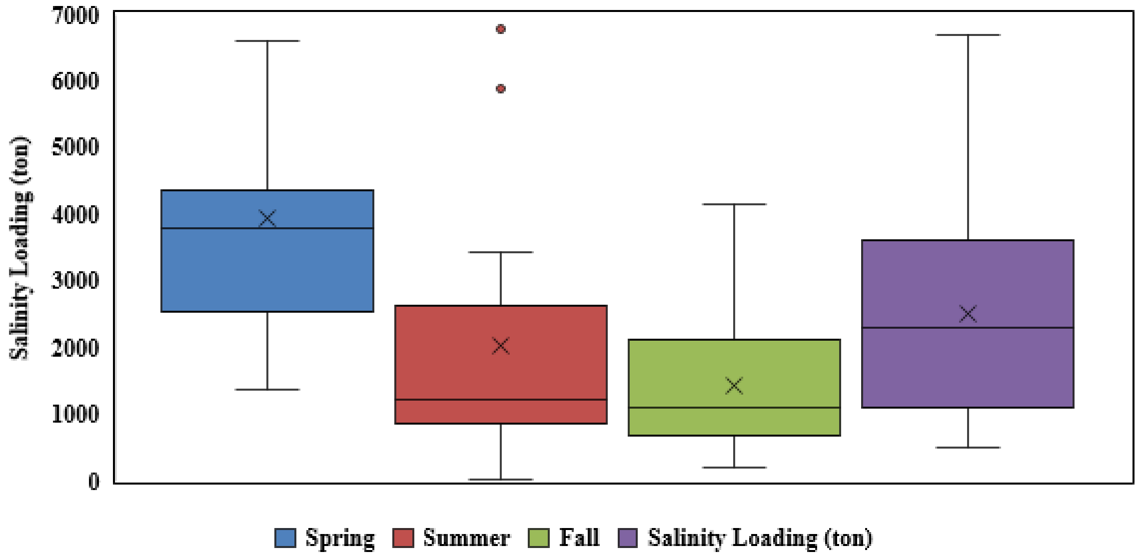


(b)

Figure 2-12: Monthly simulated salinity loading at Blackbrook Creek (a) and Marsh Creek (b)

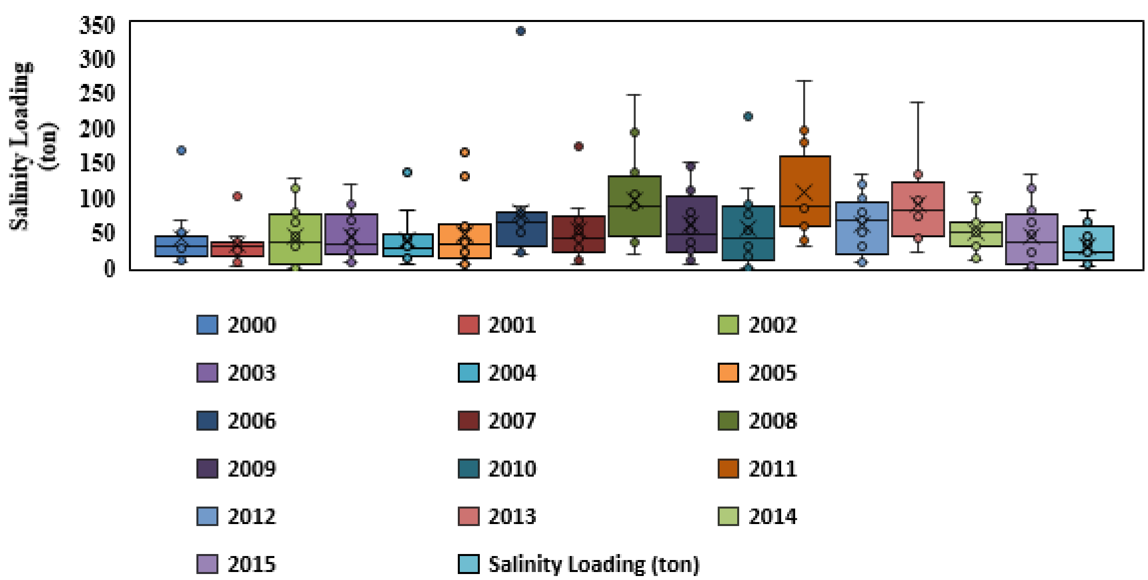


(a)



(b)

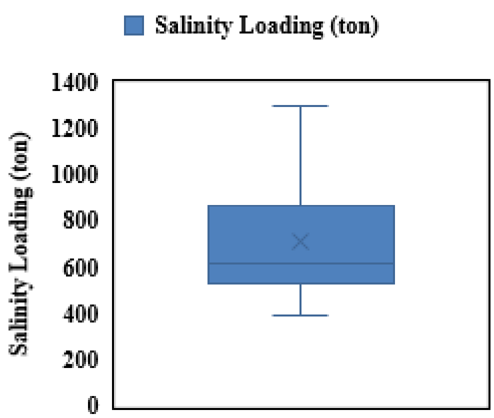
Figure 2-13: Seasonal simulated salinity loading at Blackbrook Creek (a) and Marsh Creek (b)

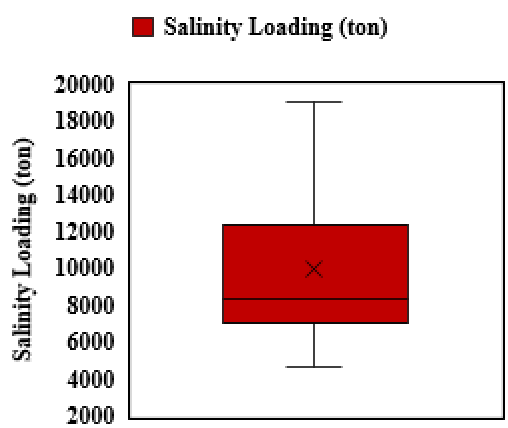


(a)

(b)

Figure 2-14: Annual simulated salinity loading at Blackbrook Creek (a) and Marsh Creek (b)





(a) (b)

Figure 2-15: Total annual simulated salinity loading at Blackbrook Creek (a) and Marsh Creek (b)

Table 2.1 Percentage of land cover in Mentor Marsh watershed

Land Cover	Percentage
Open Water	0.23
Developed, Open Space	32.33
Developed, Low Intensity	40.55
Developed, Medium Intensity	9.5
Developed, High Intensity	2.4
Barren Land	0.32
Deciduous Forest	8.79
Evergreen Forest	0
Shrub/Scrub	0.03
Grassland/Herbaceous	3.11
Hay/Pasture	1.07
Woody Wetlands	1.66
Emergent Herbaceous Wetlands	0.03

Table 2.2 Model parameters used in SWAT calibration

Parameters	Calibrated Value
CN (relative)	65.3
ESCO	0.98
EPCO	0.98
GW-delay	10
Alpha-bf	0.5
Gw-Revap	10
Sol- Awc	0.118
SMFMX	3
TIMP	0.75
SMFMN	3
SMTMP	4
SFTMP	2.51

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Appendices

Finalizing the monitoring site in Marsh Creek (Mr. Bruckman, Dr. Sharma, Mr. Edgar)

Streamflow recording in Blackbrook Creek (Mr. Hari Dhungel)

Streamflow recording in Marsh Creek (Dr. Sharma, Mr. Edgar and Mr. Dhungel from left)

Flow Measurement in Blackbrook Creek (Mr. Hari Dhungel)

Monitoring sites in Marsh Creek with public notice

LAKE ERIE PROTECTION FUND

SMALL GRANT - FINAL ACCOUNTING

Grant Number: SG 576-17

v2017

Budget Categories	Original Budget	Funds Spent	Current Balance	Matching Funds
A. Salaries & Wages				
Graduate Assistant	$7,000.00	$7,460.54	$(460.54)	
PI Summer Salary (9 days)	$3,348.00	$3,348.00	$0.00	
PI Release Wages (1 Semester Hour)				$2,790.13
B. Fringe Benefits				
GA 5%*$7,000	$350.00	$373.07	$(23.07)	
PI 17%*$3,348	$569.00	$569.16	$(0.16)	
PI Release Fringe Benefits (33%)				$920.74
C. Total Salaries & Benefits (A+B)	$11,267.00	$11,750.77	$(483.77)	$3,710.87
D. Non-expendable Equipment				
E. Expendable Materials & Supplies				
F. Travel				
Travel for site visits	$1,933.00	$1,571.50	$361.50	
G. Services or Consultants				
Mentor City Staff	$500.00	$0.00	$500.00	
H. Computer Costs				
I. Publications/Presentations				
J. All other direct costs				
K. Total Direct Costs (C thru J)	$13,700.00	$13,322.27	$377.73	$3,710.87
L. Indirect Costs				
IDC 10% of total	$1,300.00	$1,300.00	$0.00	$1,478.77
Total Costs (K + L)	$15,000.00	$14,622.27	$377.73	$5,189.64

I certify that the grant expenditures listed and descriptions of the charges are true and accurate to the best of my knowledge. These expenditures represent approved grant costs that have been previously paid for and for which complete documentation is on file.

Ohio Lake Erie Commission 347 North Dunbridge Road Bowling Green, Ohio 43402
p 419-357-277 5

lakeerie.ohio.gov

Ohio | Lake Erie Protection Fund

	Signature	Date
Project Director	[signature]	8/31/2018
Authorizing Agent	[signature]	8/31/2018
Fiscal Agent	[signature]	8.30.18