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List of Abbreviations

BMPs	best management practices
CN	curve number
H&H	Hydrologic and Hydraulic
HEC-RAS	Hydrologic Engineering Center’s River Analysis System
IRM	Indian Ridge Marsh
ISWS	Illinois State Water Survey
msl	mean sea level
NRCS	Natural Resources Conservation Service
SWMM	Storm Water Management Model

Abstract

Lake Calumet is located south of Lake Michigan. It is a site of former landfills and abandoned industrial facilities, yet a place of economical and ecological significance for the future development of the area. The marshes surrounding Lake Calumet are ecologically significant to the Black-crowned Night Heron but the hydrology in the area has been greatly impacted by the large amount of landfilling and the constantly changing land use and drainage of the surrounding uplands. In order to save threatened species, to prevent ecosystem degradation, and recreate a local economic base, the City of Chicago's Department of Environment has been leading community groups and other agencies to develop plans to restore the region to a recreational area. Millions of dollars will be invested for the effort.

To support the development plan for the Calumet Region to become an ecological park, hydrologic and hydraulic models have been developed for the region. These models serve as a basis for determining the best water management strategies for the Lake Calumet Cluster Sites and the adjacent open spaces, namely the Indian Ridge Marsh (IRM). An integrated hydrologic and hydraulic model was used to evaluate the hydrologic impacts of different remedial options proposed for the Cluster Sites and other upland properties in the marsh watersheds, and to assess the adequacy of the existing marsh outlets in terms of long-range ecological goals. This report evaluates six proposed management scenarios to cope with flooding and to establish a more suitable environment for Black-crowned Night Heron nests in the marsh areas by controlling water level fluctuations. For Black-crowned Night Heron nests, the maximum fluctuation is ten inches. Our study showed that diverting surface runoff from the Cluster Sites appeared to be the best option for limiting water level fluctuations to around six inches in the IRM.

Introduction

The hydrology of the ecologically significant marshes surrounding Lake Calumet has been greatly affected by landfilling, constantly changing land use, and drainage of the uplands. Historically, these marshes were directly connected to Lake Calumet, which drained through the old shallow meandering Calumet River to Lake Michigan. The current outlets of the marshes consist of dams and culverts which have been largely uncontrolled. When flow through these outlets is unrestricted, the marshes tend to dry up. When outlets are blocked, however, the marshes flood, damaging the habitat and creating problems for the surrounding residences, roadways, and railways. The marshes are subject to prolonged flooding when Lake Michigan's water level exceeds 582 feet above mean sea level (msl), such as the period from early 1985 to early 1987. Previous Illinois State Water Survey (ISWS) modeling efforts show that the creation of an ideal hydroperiod (the period in which a soil area is waterlogged) for a wetland attached to the Great Lakes can be accomplished at Indian Ridge Marsh (IRM). This statement assumes the outlet at the Calumet River has an elevation of 580.5 feet-msl and that flow is unrestricted through the culvert under 122nd Street. However, over the years, the culvert has been periodically blocked by local fishermen or more recently by beaver dams. The installation of beaver-proof fencing at the culvert has helped keep the flow open; unfortunately, beavers tend to relocate to wherever there is moving water in the channel in the Indian Ridge Marsh area (Figure 1).

The existing marshes surround a square 275-acre parcel of former marshland that has been filled in. On the west side of the parcel are two large elevated landfills, Land and Lakes III and Paxton II, with the latter being over 150 feet high with slopes that exceed 40%. The east side of the parcel is a relatively flat plateau with landfill up to 30 feet thick. This area is comprised of the at-grade Paxton I landfill and the four cleanup sites of Alburn Incinerator, US Drum, Paxton Lagoons, and the Unnamed Parcel, collectively known as Lake Calumet Cluster Sites. Because the area was built up over a long period of time, apparently without a master plan, the internal drainage on the site is very haphazard.

Hydraulically the scattered ponds and low spots provide enough internal storage to accommodate smaller rain events. Prior to the grading at Paxton I in the northeastern 30 acres of the site, storm water overflowed in all four directions: north by large sheet flows into Big Marsh, east through culverts under the railroad tracks into IRM, south over 122nd Street or through culverts to Dead Stick Pond, and west over Stony Island Avenue towards Lake Calumet. The re-grading at Paxton I and II now routes water in a counter-clockwise pattern around the two Paxton parcels that end at the culvert draining Big Marsh into Lake Calumet.

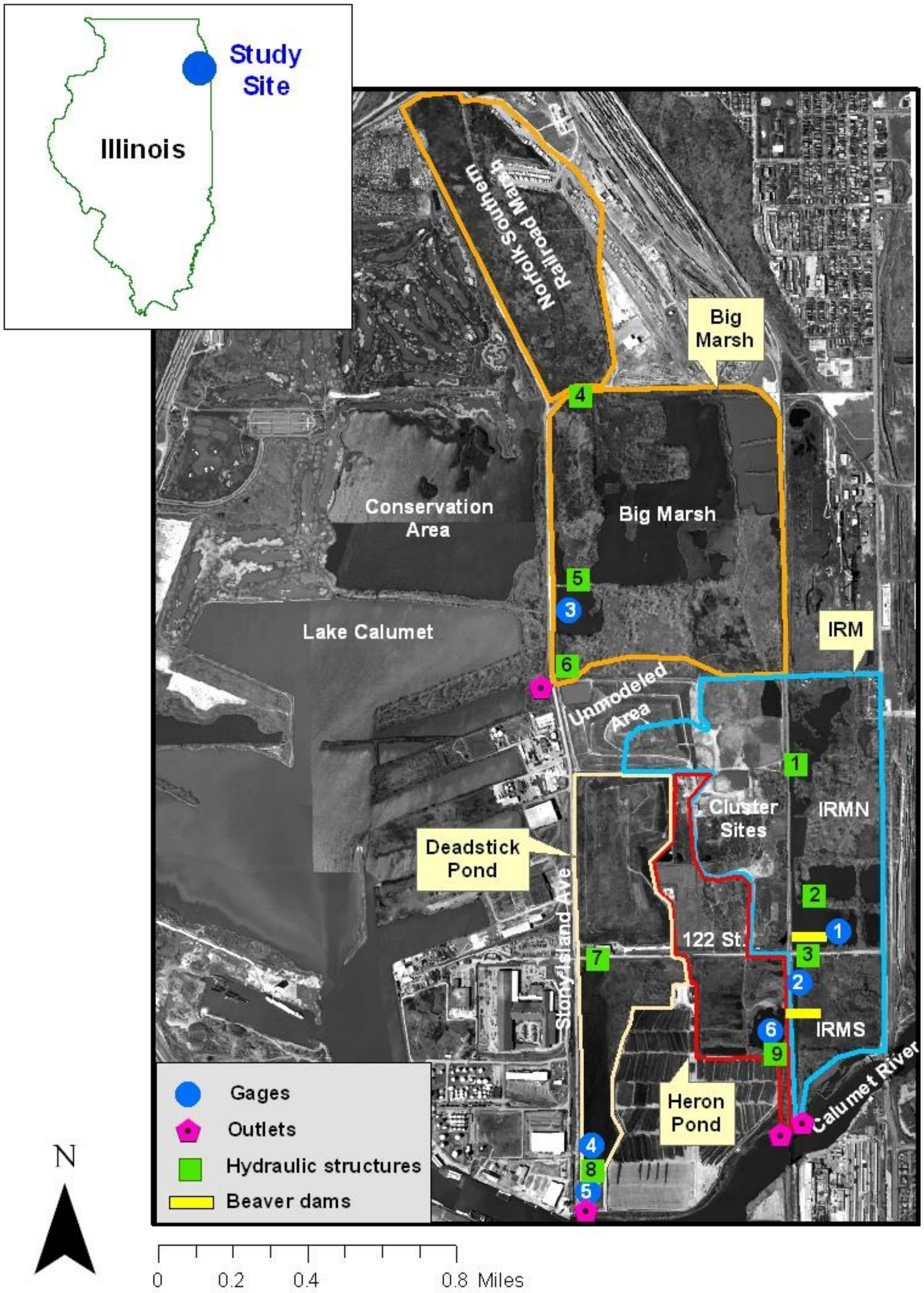

Figure 1. Map of the Calumet Study Area.

A potentiometric surface map constructed by Ecology and Environment, Inc. for the Cluster Sites and Paxton I shows that groundwater generally flows east towards the marsh. Groundwater discharges as seepages that occur between 118th and 120th Streets in the central third of the site. High rates of infiltration with little to no overland runoff have been observed on the slag piles surrounding the northeastern portion of Big Marsh (Duwal, 1994). If we assume a moderately high range of net infiltration rates to the water table of between 6 in/yr to 10 in/yr on 132 acres of the Cluster Sites and Paxton I, then the average discharge to the marsh should be on the order of 8,000 ft^3/d to 13,000 ft^3/d. If a clay cap was placed over the sites, the infiltration rate would be less than 2 in/yr, thus lowering the groundwater discharge to less that 2,700 ft^3/d. From the SWAMPMOD model applied to IRM (Roadcap et al., 1999), it was estimated the total groundwater discharge into the marsh from all sides as 18,500 ft^3/d (0.21 cfs or 0.42 acre-feet/day). The sensitivity analysis of the model parameters shows that reducing the groundwater inflow by 25% to 13,900 ft^3/d would not have an impact on the water level of the marsh. As long as the water level in the marsh is being controlled at a set elevation at the outlet, shutting off groundwater discharge from the Cluster Sites should have little impact on water levels in the marsh except during the case of an extremely dry summer coupled with an unusually low water level in Lake Michigan.

In 2007, a portion of the Cluster Sites was capped with a low permeability clayey layer to limit infiltration of contaminated water into the groundwater thus reducing potential contamination of the IRM. On the other hand, capping at the Cluster Sites has increased the surface flow runoff from rainstorm events and has subsequently increased the water level fluctuations in the IRM.

The Black-crowned Night Heron nests in the marsh areas around the Cluster Sites are near the water line. To protect the nests, the water level fluctuations during a storm event must be kept to a minimum. Currently, some of the most severe flooding occurs near where the Black-crowned Night Herons nest. However, general flooding is also a concern. As can be seen during the onsite visits after storms, water overtopped Torrance Avenue on the east edge of the marsh and resulted in hazard for traffic.

The main objectives of the study are to develop hydrologic and hydraulic models for the Lake Calumet area and assist the effort in restoring the area into an eco-friendly park. In order to accomplish the goals of this study, we have carried out the following three tasks: performing Hydrologic and Hydraulic (H&H) modeling of the study site, conducting critical storm duration analysis, and investigating several possible management scenarios to provide a suitable environment for the Black-crowned Night Heron nests in the marsh areas through controlling the water level fluctuations.

Development of Hydrologic and Hydraulic Models

There are four flow outlets in the Calumet area: one for Big Marsh to drain into the Lake Calumet, and three others for Indian Ridge Marsh, Deadstick Pond and Heron Pond to drain into the Calumet River at different locations along the river (Figure 1). Six gauges were installed in 2003 for the Hydrologic Master Plan (V3 2006) to monitor water levels in those four water bodies (Table 1) and continuous stages have been collected in 15-minute time interval. The drainage system in the area has been disturbed by human and other activities. There are nine hydraulic structures (culverts) associated with the outlets, roads and railroad (Table 2) and two beaver dams.

The Calumet Area was divided into four modeling areas: Indian Ridge Marsh (IRM), Big Marsh, Deadstick Pond, and Heron Pond. Hydrologic and hydraulic models have been constructed for each of the areas. The models were calibrated and validated for the IRM including Cluster Sites, and for Big Marsh.

Table 1. List of gages in the Calumet Study Area.

Table 1. List of	V3 Gage ID	Location	Descriptions
1	ASG4	Indian Ridge Marsh	Indian Ridge Marsh north pool
2	ASG5	Indian Ridge Marsh	Indian Ridge Marsh south pool
3	ASG2	Big Marsh	Big Marsh south pool
4	ASG3	Big Marsh	South end of Big Marsh
5	ASG7	Deadstick Pond	Deadstick Pond pool
6	ASG8	Deadstick Pond	Deadstick Pond outfall
7	ASG6	Heron Pond	Heron Pond pool

Table 2. List of hydraulic structures in the Calumet Study Area.

Hydraulic Structure No.	Location	Descriptions
1	Indian Ridge Marsh	Cluster Sites to North Indian Ridge Marsh
2	Indian Ridge Marsh	Storage Pond in North Indian Ridge Marsh
3	Indian Ridge Marsh	North IRM to South Indian Ridge Marsh
4	Big Marsh	Norfolk Southern Railroad Marsh to Big Marsh
5	Big Marsh	Northern pond to southern pond in Big Marsh
6	Big Marsh	Big Marsh to Lake Calumet
7	Deadstick Pond	Deadstick Pond North to Deadstick Pond South
8	Deadstick Pond	Deadstick Pond South to the Calumet River
9	Heron Pond	Heron Pond to the Calumet River

Methodology

The hydrologic models were developed using the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) version 5.0 (USEPA, 2007). The US Army Corps of Engineer Hydrologic Engineering Center's River Analysis System (HEC-RAS) was utilized to route the flow in the streams or lakes.

Hydrologic Model

The EPA SWMM is a dynamic rainfall-runoff simulation model. It was initially built in 1971 and has gone through several upgrades since then. The model is capable of simulating water quality and quantity for single-event and continuous storms with urban settings. In SWMM, a watershed is subdivided into subcatchments and each subcatchment is regarded as a separate unit (Figure 2). Flow rate, flow depth, and water quality indicators are determined for each subcatchment at each time increment. Flow is then routed through a network of channels, pipes, culverts, weirs, etc, to simulate the hydraulic behavior of the system.

SWMM is a physically-based rainfall-runoff simulation model. It is based on the principles of mass, momentum, and energy. The simulation model encompasses four physical compartments (Figure 3) and seven physical processes (Figure 4). SWMM is also capable of estimating pollutant loads from runoff. SWMM is widely used worldwide and has seen success in applications such as:

- designing and sizing of drainage system components for flood control;
- sizing of detention facilities and their appurtenances for flood control and water quality protection;
- flood plain mapping of natural channel systems;
- designing control strategies for minimizing combined sewer overflows;
- evaluating the impact of inflow and infiltration on sanitary sewer overflows;
- generating non-point source pollutant loadings for waste load allocation studies; and
- evaluating the effectiveness of best management practices (BMPs) for reducing wet weather pollutant loadings.

The SWMM model in this study employs the curve number (CN) infiltration method. This method is based on the Natural Resources Conservation Service (NRCS) curve number concept. The CN method assumes that the total infiltration capacity that a soil column can withhold is a function of the soil's curve number value plus two additional parameters – the soil's saturated hydrologic conductivity and the drying time needed to drain a completely saturated soil.

The SWMM model also treats the subwatershed surface as a nonlinear reservoir and estimates surface runoff (*Q*) based on Manning's Equation:

$$Q = W \frac{1.49}{n} \left(d - d_p\right)^{5/3} S^{1/2} \tag{1}$$

where W - the subwatershed's characteristic width, n - Manning's roughness value, d - depth of water in the reservoir, d_p - the maximum depression storage, and S - hydraulic gradient. Figure 5 provides a conceptual schematic of the surface runoff mechanism in SWMM.

The groundwater flow mechanism adopted by SWMM is based on the status of the groundwater and surface water heads. Equation 2 describes that relationship.

$$Q_g = A_1\left(H_g - E\right)^{B_1} - A_2\left(H_s - E\right)^{B_2} + A_3\left(H_g \cdot H_s\right) \qquad (2)$$

where Q_g is the groundwater flow, H_g is the elevation of the water table, H_s is the elevation of surface water, E is the minimum threshold groundwater table elevation before any flow occurs, and A_1, A_2, A_3, B_1, and B_2 are coefficients.

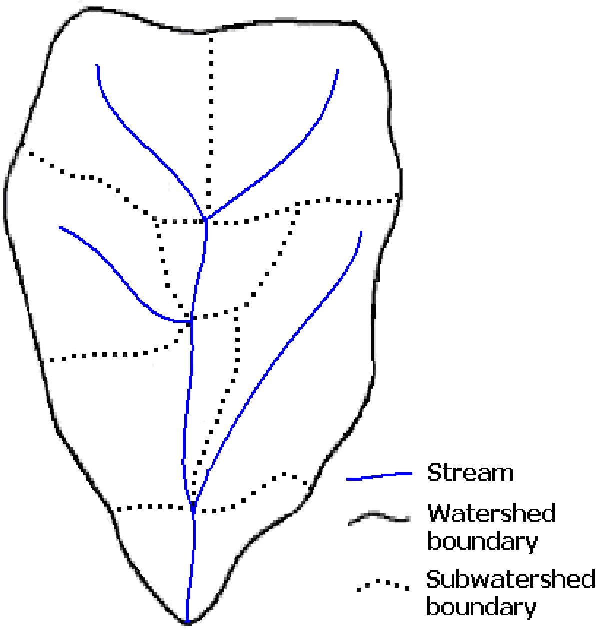

Figure 2. Schematic of a watershed model in SWMM.

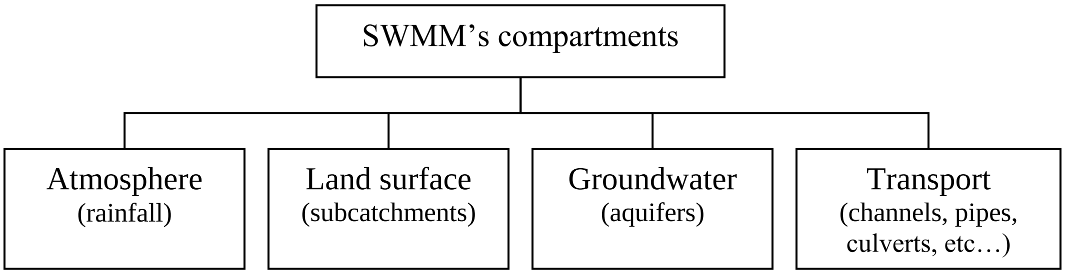

Figure 3. SWMM's conceptual model framework.

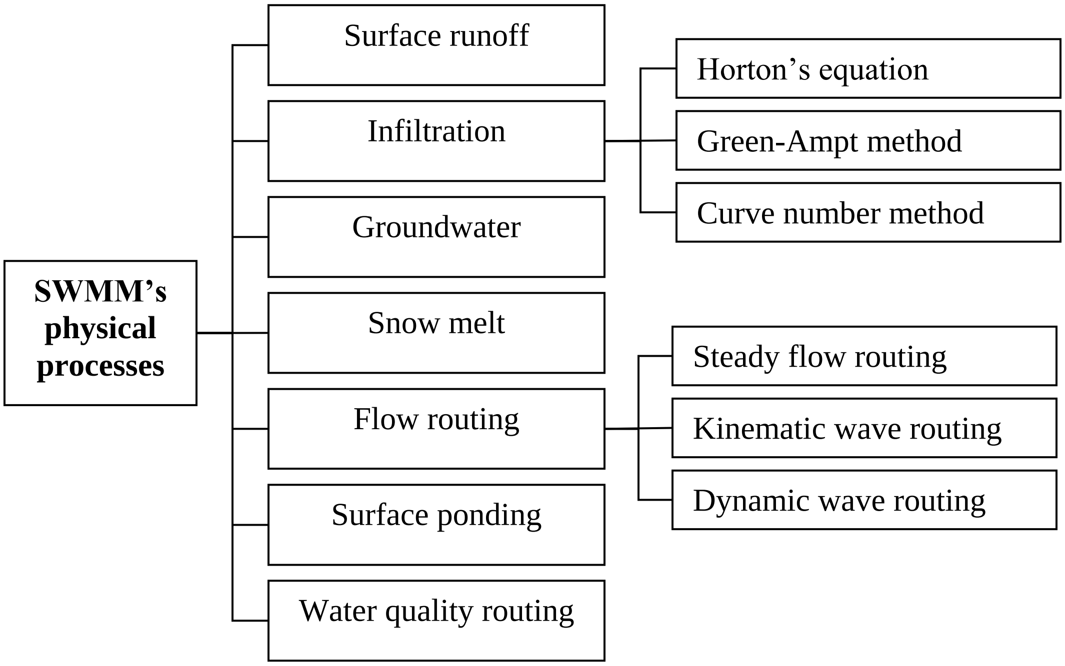

Figure 4. SWMM's physical processes.

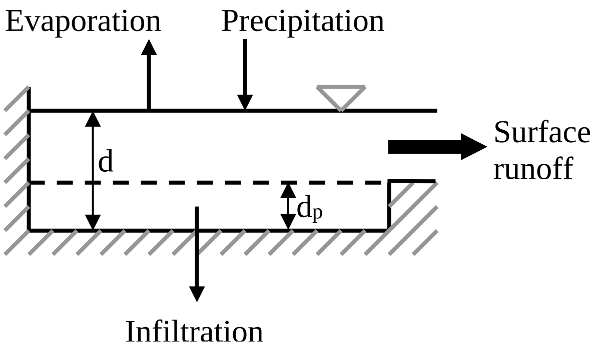

Figure 5. A conceptual schematic of the surface runoff mechanism in SWMM.

Hydraulic Model (HEC-RAS)

The U.S. Army Corps of Engineers River Analysis System (HEC-RAS) was developed by the Hydrologic Engineering Center (HEC) as a part of the "NexGen" project to establish the next generation of hydrologic engineering software. HEC-RAS is a one-dimensional hydraulic model that simulates runoff routing through a network system of channels, pipes, culverts, etc., based on the conservation principles of mass and momentum. Open channel networks along with their cross-section geometries and all existing hydraulic structures are easily incorporated into HEC-RAS to simulate the hydraulic behavior of flow in open channels. Figure 6 represents a sample schematic representation of a HEC-RAS model. Version 4.0 of HEC-RAS is capable of performing one-dimensional steady, unsteady flow, sediment transport, and water quality simulations.

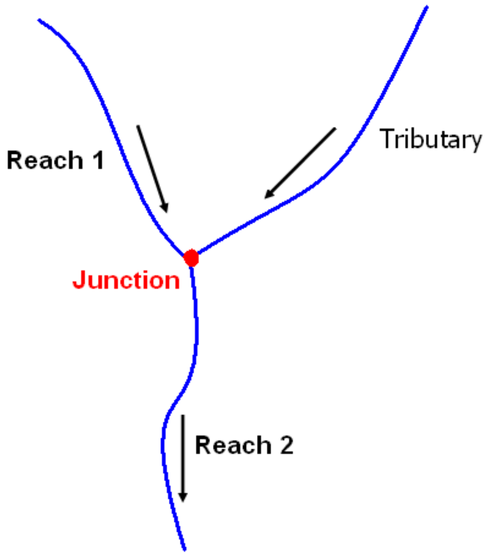

Figure 6. A schematic of a channel network representation in HEC-RAS.

All components share the same geometric representation and can be seamlessly computed in a unified framework. The steady flow computations are based on solving the 1-D energy and momentum equations; the steady flow component can model subcritical, supercritical, and mixed flow regime water surface profiles. The unsteady flow component includes the features incorporated in the steady flow component. Special features in the unsteady flow component include: dam break analysis, levee breaching and over topping, pumping stations, navigation dam operations, and pressurized pipe systems. Both steady and unsteady flow components can receive point or uniformly distributed lateral inflows from either tributaries or from adjacent watersheds. The unsteady flow computation routine is based on the UNET model solver (Barkau, 1992; HEC, 1993). The sediment transport component is capable of computing estimates of sediment transport potentials due to scours and depositions processes. The water quality component is limited to water temperature modeling in this model version; but future versions will perform water quality transport computations of several constituents. The latter two components are not included in this study.

Hydrologic Models for the Calumet Area

Over the years the Calumet area has been modified by human activities such as landfilling and construction of railroad and flow structures. Hydrologic and hydraulic models have been developed for the Big Marsh, Indian Ridge Marsh, Heron Pond and Dead Stick pond areas, which drain to either the Calumet River or Lake Calumet (Figure 1). Because SWMM does not have the capability to handle multiple outlets, a separate SWMM model is required for each outlet.

Indian Ridge Marsh (IRM)

The Indian Ridge Marsh is located on the east site of the Calumet area. After site visits and examining the topographic features of the Indian Ridge Marsh (IRM) area, six contributing subwatersheds i.e. Indian Ridge Marsh North (IRMN) upper and lower, Indian Ridge Marsh South (IRMS), Paxton II Landfill Site, Paxton I Landfill Site, and Cluster Landfill Site, were designated to be used in creating the IRM model (Figure 7). .

The Cluster Landfill Site has an internal 24 inch culvert in its northwest corner which channels flow under the entrance road to the Cluster Sites and discharges it into the rest of the Cluster Landfill Site. Because each watershed in a SWMM model must drain to only one specific point, this exact scenario could not be modeled directly and thus the Cluster Landfill Site was split into two watersheds strictly for modeling purposes.

Runoff from the three Cluster Site watersheds flows through a three culvert structure underneath the Norfolk Southern Railroad to feed in the Indian Ridge Marshes. A concrete box drop inlet structure with a concrete manhole and 4 foot diameter open grate is located in the pond just north of 122nd Street. This structure directs flow to a 24 inch corrugated metal pipe culvert which conveys the cumulative flow under 122nd Street. Modeling of the drop inlet structure and a beaver dam located in the Indian Ridge Marsh North lower section are further discussed in the hydraulic modeling section. The amount of rainfall directly feeding into the open water bodies was assumed negligible for the IRM area.

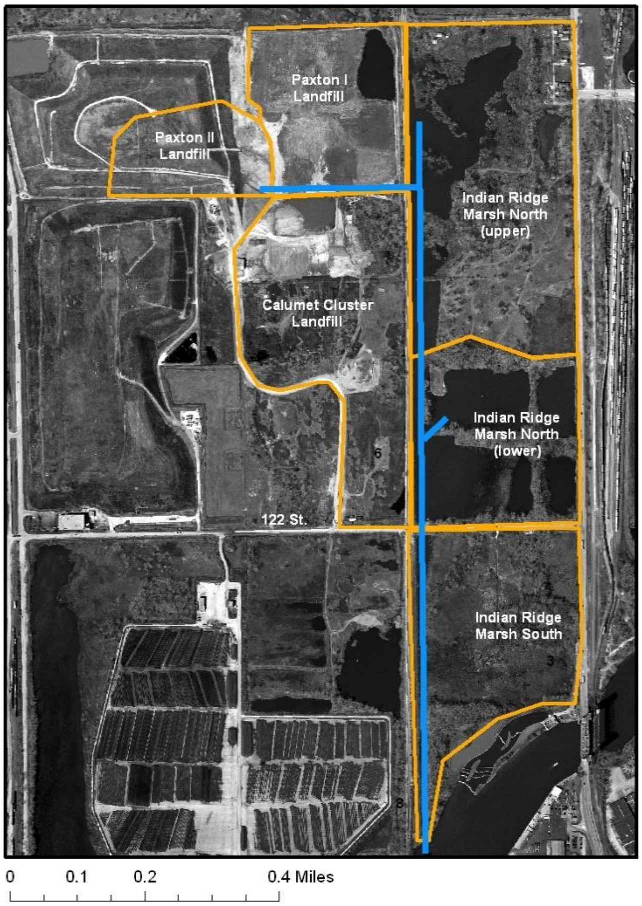

Figure 7. Model area for the Indian Ridge Marsh (IRM).

Big Marsh

The Big Marsh model covers the Big Marsh and Norfolk Southern Railroad Marsh areas and drains directly into Lake Calumet (Figure 8). The Big Marsh model divides up the area into five subwatersheds: Norfolk Southern Railroad Marsh, North Big Marsh, East Big Marsh, South Big Marsh, and West Big Marsh. The Norfolk Southern Railroad Marsh drains into Big Marsh through a 24 inch culvert running under 116th Street. Flow feeds into a large pond in Big Marsh and consequently to a relatively smaller pond downstream before water is in route to Lake Calumet via a ditch running along Stony Island Avenue. A rectangular concrete pipe drop inlet structure with twin 30 inch outlet pipes is located at the outfall of this model. A large portion of the Big Marsh watershed is open water. Due to the relatively large open-water portion of the Big Marsh site area, rainfall to the open water bodies are accounted for as direct runoff into the two existing ponds.

Evaporation from open-water bodies was estimated to be equal to potential evapotranspiration (PET) data in IRM and Big Marsh. This should yield a reasonable first order approximation of total evaporation (Ken Kunkel, ISWS, personal communication). Water loss due to evaporation was estimated for each of the water bodies in IRM and Big Marsh by adjusting the PET values to reflect the water bodies surface areas. The water loss hydrographs due to evaporation are imported in the HEC-RAS models as sinks at the locations of the water bodies.

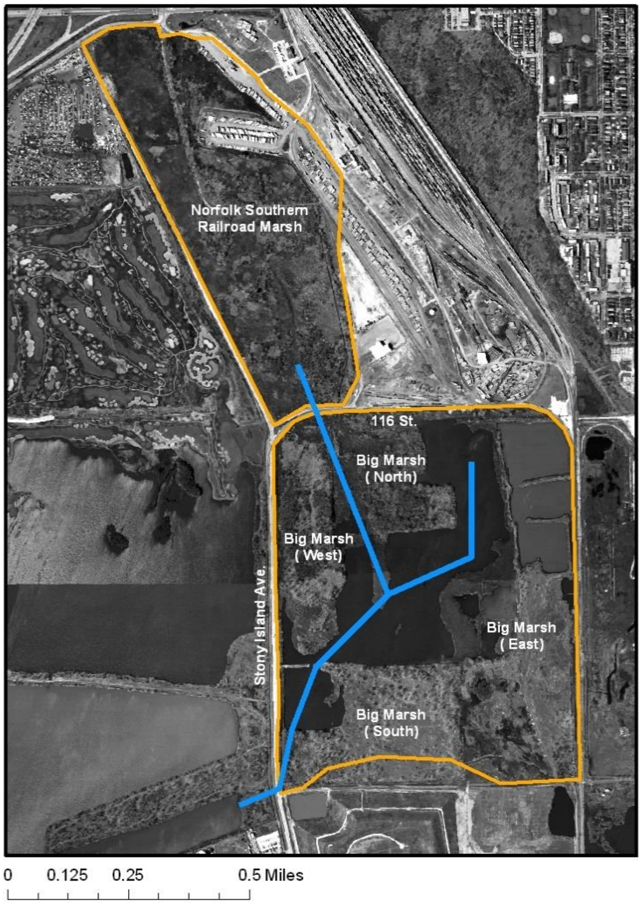

Figure 8. Modeled area for the Big Marsh.

Deadstick Pond

The Deadstick Pond area is divided into two subwatersheds: North and South. The two subwatersheds are connected hydrologically through a culvert that extends underneath 122nd Street (See Figure 9). The culvert discharges into a channel feeding into the Deadstick Pond. Additionally, runoff from the southern subwatershed feeds laterally in the Deadstick

Pond. The stage of the Deadstick Pond is controlled by a drop inlet structure at the downstream end before discharging into the Calumet River.

Heron Pond

The Heron Pond area did not necessitate any further sub-division and was modeled as a single unit area (Figure 10). Runoff directly feeds in the Heron Pond at the downstream end of the drainage area. The pond stage is controlled by a rudimentary man-made weir structure. The outflow through the weir flows into an open channel draining into the Calumet River.

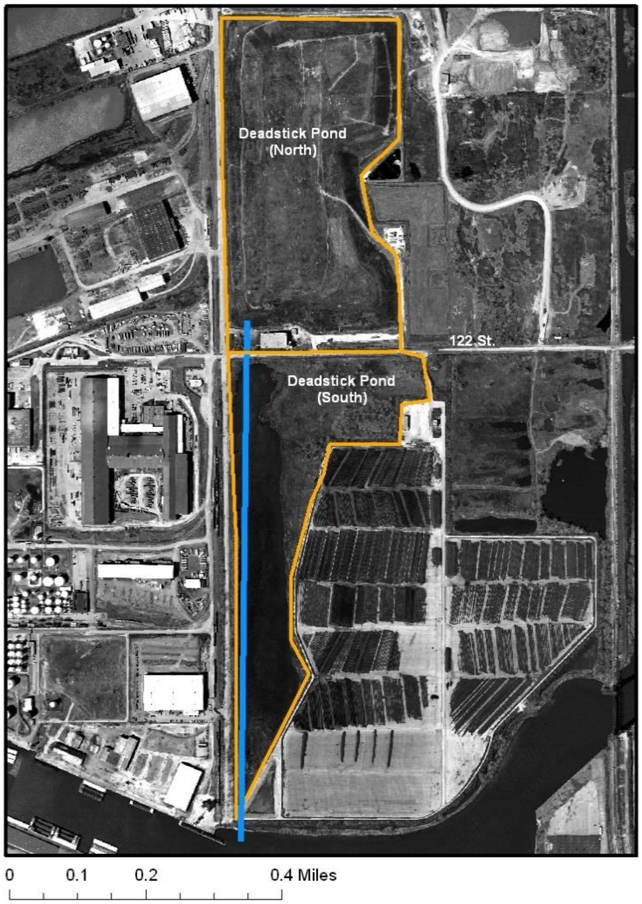

Figure 9. Modeled area for the Deadstick Pond.

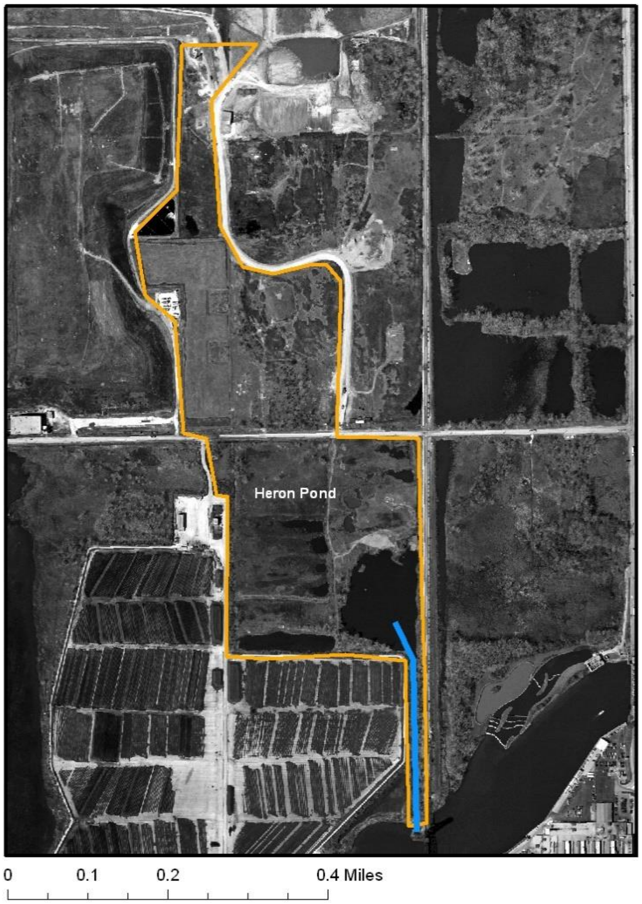

Figure 10. Modeled area for the Heron Pond.

Hydraulic Models for the Calumet Area

Analysis of simulation results using the 100-year design storm of the Indian Ridge Marsh SWMM model revealed a large backwater effect upstream of the 122nd Street culvert. Although some backwater effects are to be expected from such a storm, the excessive backwater effects were attributed to deficiencies in the SWMM model in accurately portraying uniform lateral inflows from surrounding watersheds during a storm. Because the EPA SWMM 5.0 was designed for urban storm runoff, it lacks the option to receive uniform lateral inflow into channels. Instead, the US Army Corps of Engineer Hydrologic Engineering Center's River Analysis System (HEC-RAS) was utilized for stream flow routing. SWMM was strictly used to generate runoff hydrographs from each of the individual subwatersheds and HEC-RAS was subsequently used to route flow through the channels. The coupling of a hydrologic model and a hydraulic model allowed for a more accurate modeling of flood stages in the area, and subsequently a more acceptable fitting performance to the observed stage data.

A hydraulic model was established for each of the four delineated areas in Figure 1. The hydraulic models take as input the runoff hydrographs generated by the SWMM models. HEC-RAS was used as the hydraulic model of choice for three of the areas: IRM, Big Marsh, and Deadstick Pond. Those areas possess uniform lateral inflows which cannot be modeled by SWMM; thus, HEC-RAS replaced the hydraulic component of SWMM for those models. With respect to Heron Pond, because no lateral inflow is necessary to model the hydraulic behavior of the watershed system, the use of SWMM for both hydrologic and hydraulic modeling sufficed for this area.

To accurately model the hydraulic behavior of the four areas, reliable cross-sectional data along the reaches is very crucial for adequate representation. Cross-sections for the IRM and Big Marsh channels were provided in reports by V3, a consulting firm; however, many of the cross sections were either incomplete or incorrect. The digital elevation data (DEM) and bathymetry data were used to extend some of the surveyed cross sections by V3 and to create channel cross sections for use in each model. Much of the area in the Indian River Marsh sections is marsh type land and open water surface area is becoming increasingly smaller due to continued growth of dense weeds. Taking this fact into consideration along with the capabilities of HEC-RAS, it was determined that the best modeling approach would be one that includes the marsh area as overbank area in the channel cross section. The same approach was adopted when creating cross-sections for reaches of Big Marsh and Deadstick Pond. Greater details about each of the four hydraulic models and their components are presented next.

Indian Ridge Marsh (IRM)

The Indian Ridge Marsh HEC-RAS model includes three reaches: IRM-North, IRM-South, and IRM-Cluster. The IRM-North and IRM-Cluster reaches converge to form the main (IRM-South) reach. Runoff from Paxton II Landfill subwatershed feeds at the most upstream point of the IRM-Cluster reach as a lateral inflow hydrograph. Similarly, runoff from Cluster Landfill and Paxton I Landfill subwatersheds feed into the IRM-Cluster reach as uniform lateral inflow. Runoffs from the Indian Ridge Marshes flows west into the IRM-North and IRM-South reaches as uniform lateral inflow. Figure 11 shows the schematic of the HEC-RAS model for the IRM area.

There exist three hydraulic structures and two beaver dams in total in the IRM (See Figures 1 & 11). In IRM, runoff from Paxton I Landfill and Cluster Landfill flows through three culvert structures (Structure 1/Figure 12) underneath the Norfolk Southern Railroad and into the North IRM. The off-stream pond (Structure 2/Figure 13) is connected to the IRM-South reach during high flow and behaves as a separate storage when water level drops below the opening to the reach. Directly upstream of the 122nd street, a drop inlet structure (Structure 3/Figure 14) controls the water level in the IRMN and also connects the north and south streams through a culvert underneath the street. One of the two beaver dams was built around this drop inlet.

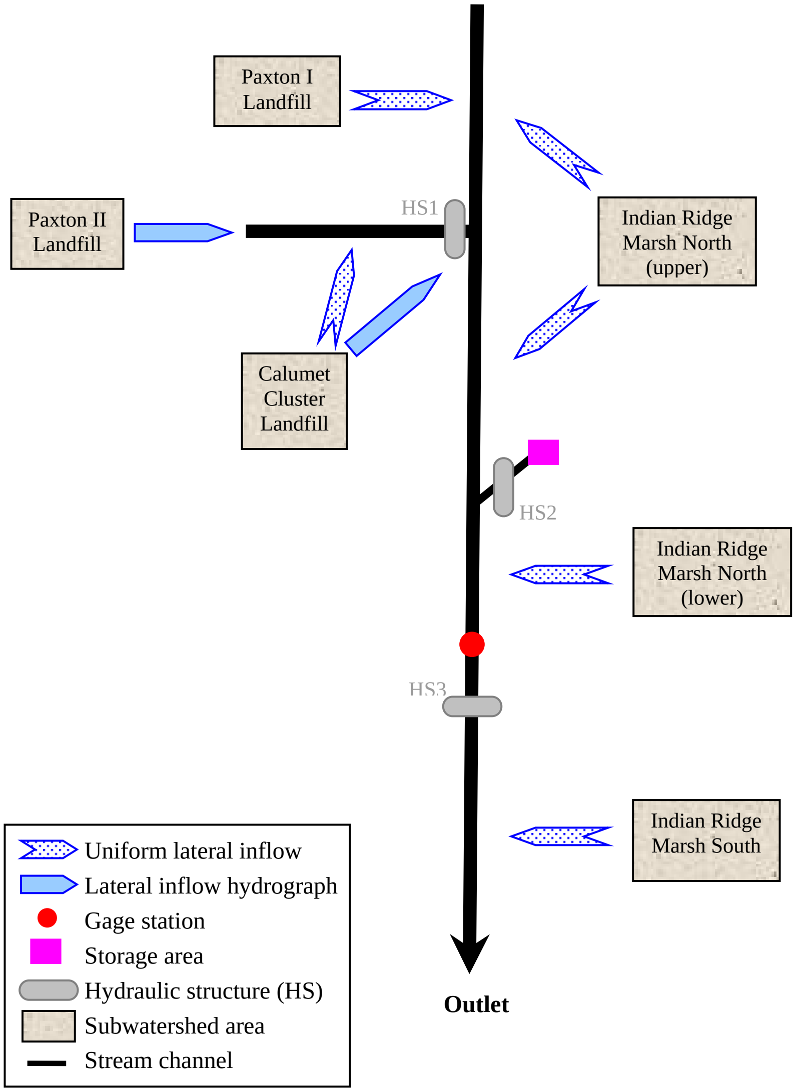

Figure 11. A schematic for the IRM HEC-RAS model.

Beavers built two dams around outflow structures on the IRM stream. The first one was around the drop inlet structure above the 122nd street. The second one is near the outlet of the IRMS (Figure 1). The two beaver dams on the IRM stream channel present a tremendous challenge to the hydraulic modeling. Both beaver dams are modeled as weir structures in HEC-RAS (USACE, 1997).

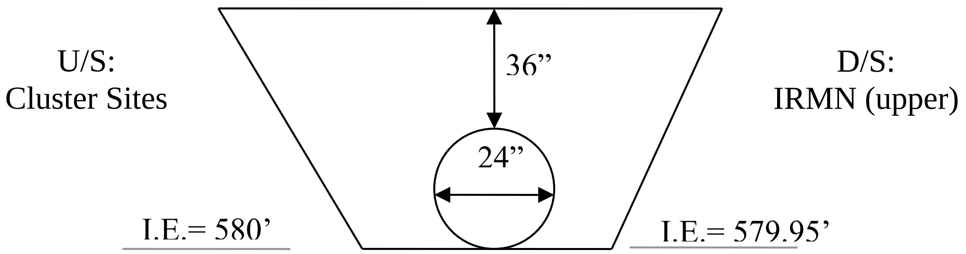

Figure 12. A culvert structure connecting Cluster Sites to IRMN (upper) (Structure 1).

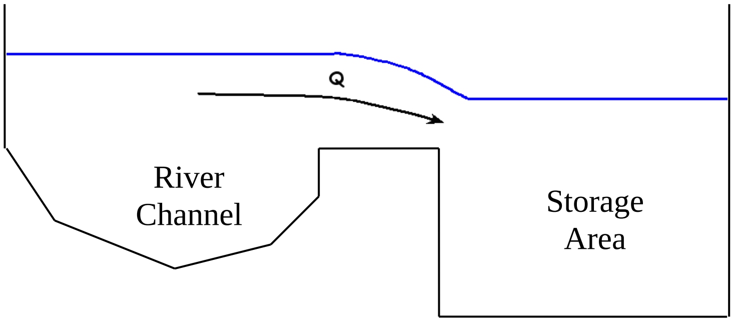

Figure 13. Storage Pond in IRMN (lower) laterally connected to the IRM reach (Structure 2).

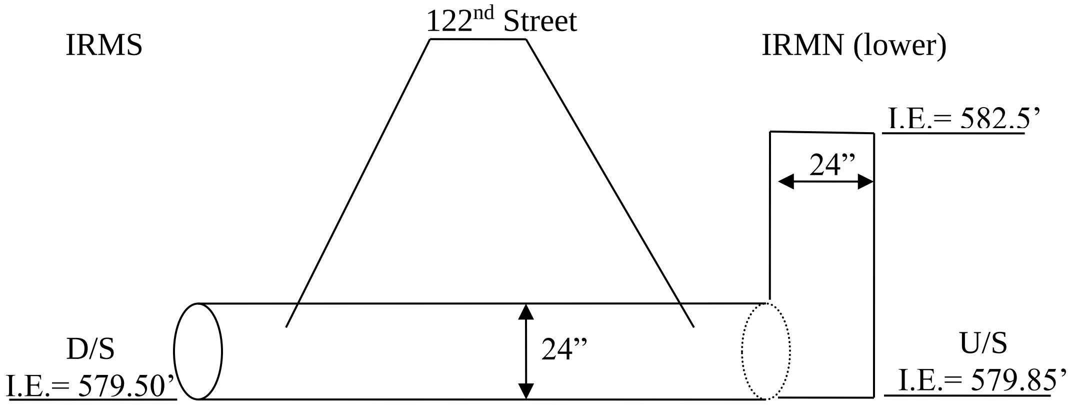

Figure 14. A culvert structure connecting IRMN (lower) to IRMS (Structure 3).

Big Marsh

The Big Marsh HEC-RAS model also includes three reaches: the Norfolk Reach, North Reach and South Reach. The Norfolk Reach and North Reach converge to form the South Reach which flows to Lake Calumet. The Norfolk Southern Railroad Marsh runoff feeds into the most upstream point of the Norfolk Reach as a lateral inflow hydrograph. Runoff from the North, West and East Big Marsh subwatersheds are further divided since they feed into more than a single reach. A detailed contour map of the Big Marsh site was used to delineate the percentage of runoff flowing into each reach. For instance, 61% and 39% of the runoff from the North Big Marsh subwatershed feed uniformly into the Norfolk Reach and North Reach, respectively. Similarly, 20% and 80% of the runoff from the West Big Marsh subwatershed feed uniformly into the Norfolk Reach and South Reach, respectively. The runoff from East Big March is divided into three components, two feeding uniformly in the North Reach and one in the South Reach with 9%, 73%, and 18%, respectively. Runoff from the South Big Marsh subwatershed flows uniformly into the downstream portion of the South Reach. See Figure 15 for a detailed schematic of the HEC-RAS model components for Big Marsh area.

In Big Marsh, there are also three hydraulic structures. Runoff from the Norfolk Southern Railroad Marsh subwatershed runs through a 24” culvert (Structure 4/Figure 16) under 116th Street. Downstream of the point where Norfolk and North reaches join, a weir structure (Structure 5/Figure 17) controls the flow between the Northern (large) Pond and the Southern (small) Pond in Big Marsh. At the outlet, a drop inlet structure with twin 30” diameter outlet pipes (Structure 6/ Figure 18) routes runoff from the Big Marsh Model into Lake Calumet.

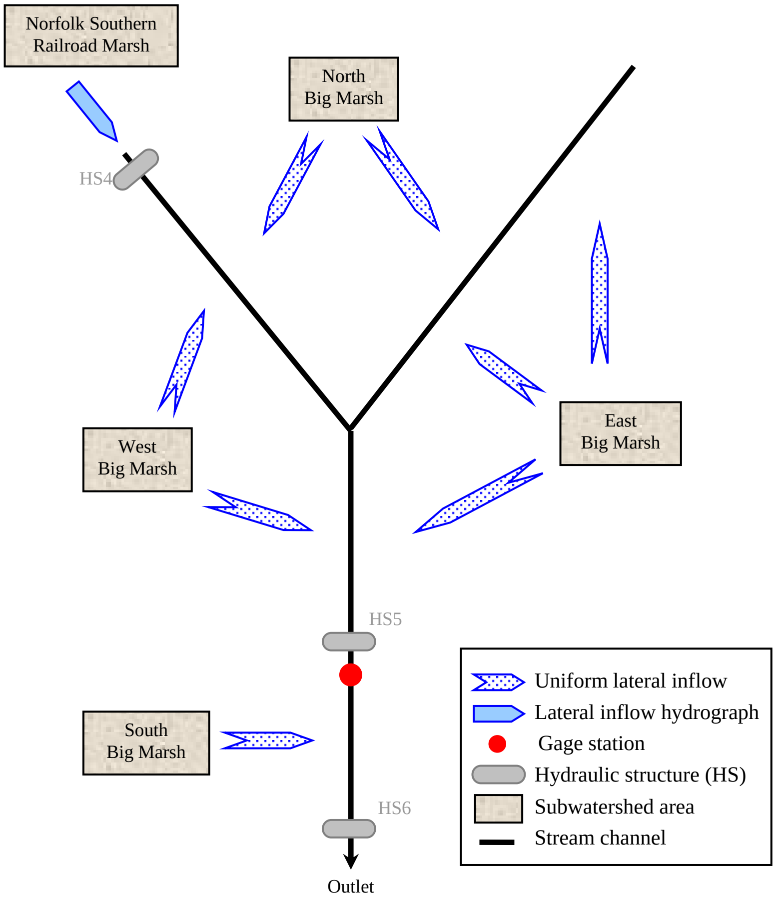

Figure 15. HEC-RAS schematic of Big Marsh model.

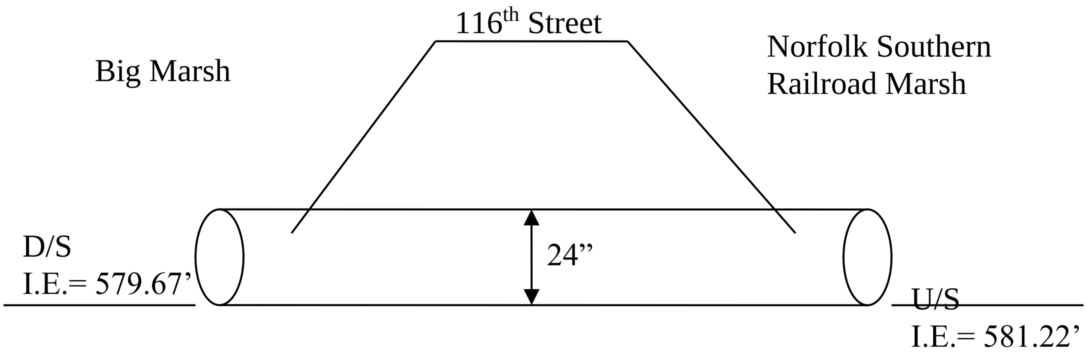

Figure 16. A culvert structure connecting Norfolk Southern Railroad Marsh to Big Marsh (Structure 4).

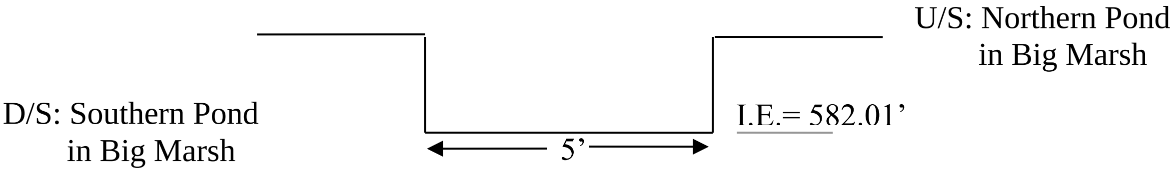

Figure 17. A weir structure connecting the northern and southern ponds in Big Marsh (Structure 5).

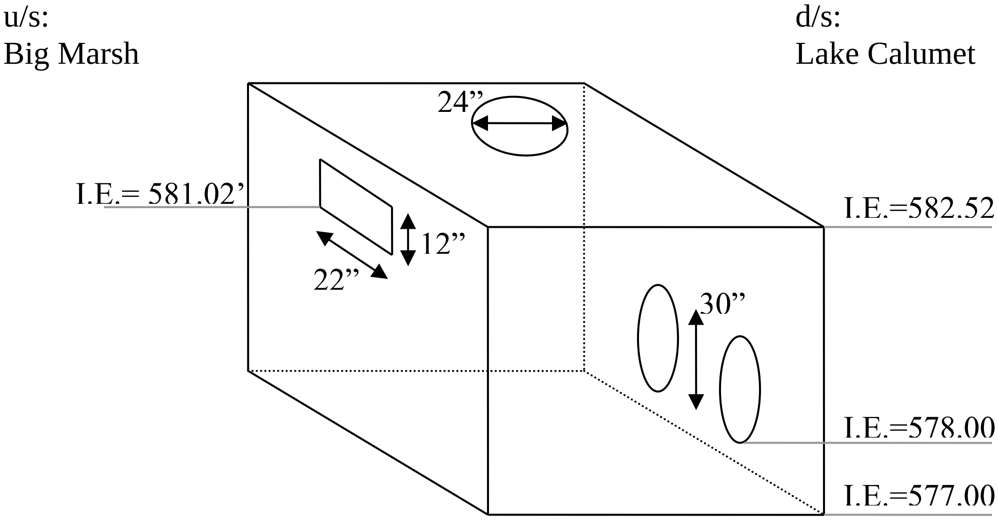

Figure 18. A drop inlet structure connecting Big Marsh to Lake Calumet (Structure 6).

Deadstick Pond

The HEC-RAS model of Deadstick Pond consists of a single reach with two subwatersheds and two hydraulic structures (Figure 19). Surface runoff from the Northern Deadstick Pond area is linked to the most upstream point of the channel reach as a lateral inflow hydrograph. The flow is routed through a single 36” diameter culvert structure (Structure 7/Figure 20) before feeding into the Deadstick Pond. Runoff from the Southern Deadstick Pond area is linked to the channel reach as uniform lateral inflow. Outflow into the Calumet River is controlled by a rectangular concrete drop inlet with an 18” diameter outlet pipe (Structure 8/Figure 21); it is located at the most downstream point of the channel reach.

Heron Pond

Unlike the previous three modeled drainage areas, SWMM was used to simulate the hydraulic model of choice for Heron Pond. Surface runoff from the overland area flows directly into Heron Pond. The pond is controlled by a weir structure as depicted in Figure 22. Outflow from the weir structure flows into an open channel linked directly to the Calumet River system.

The stage-storage relationship for the Heron Pond was estimated based on the available bathymetric contour maps of the pond. The stage-storage relationship of Heron Pond is shown in Figure 23.

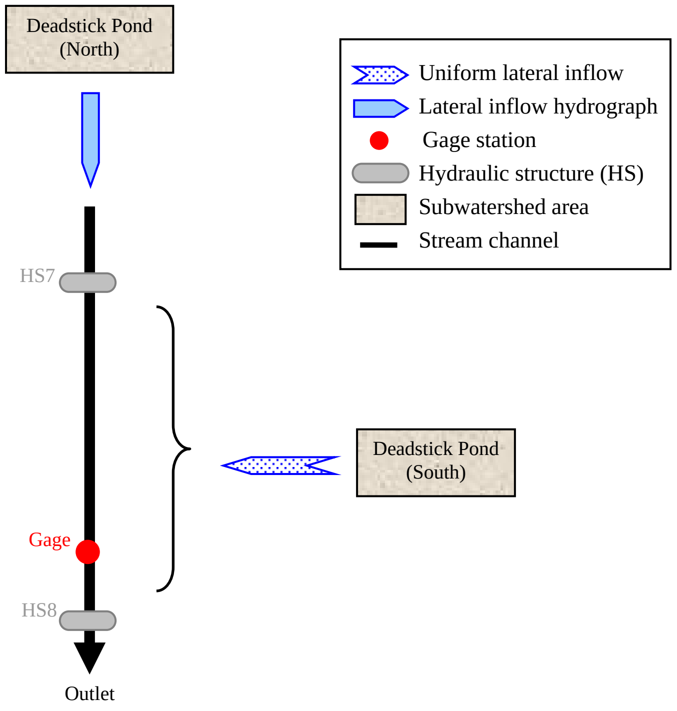

Figure 19. HEC-RAS schematic of Deadstick Pond model.

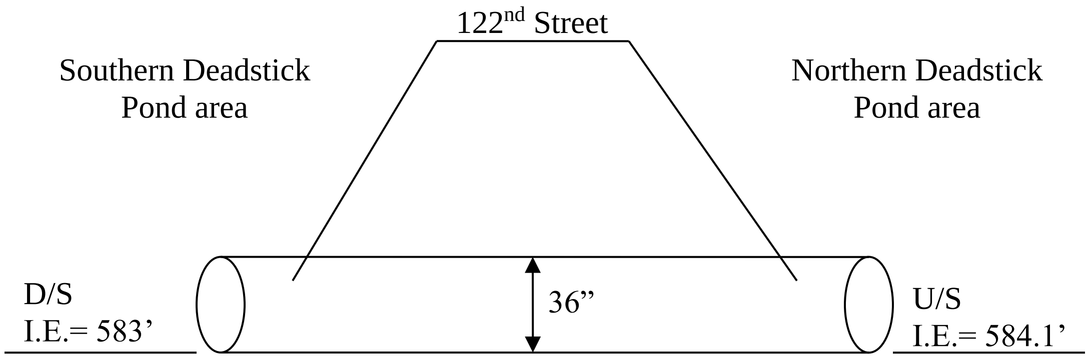

Figure 20. A culvert structure connecting the Northern and Southern Deadstick Pond areas (Structure 7).

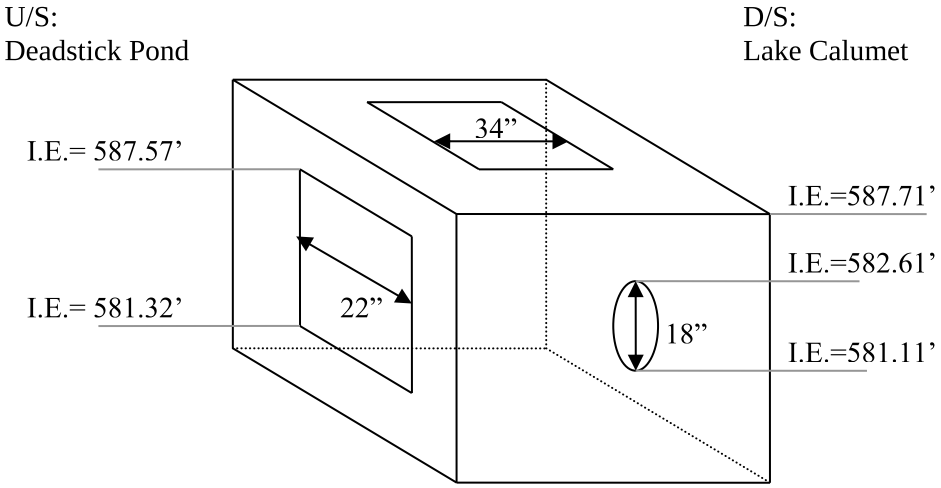

Figure 21. A drop inlet structure connecting the Deadstick Pond area to Lake Calumet (Structure 8).

Integration of Hydrologic and Hydraulic Models

A flowchart of the hydrologic-hydraulic models coupling and calibration procedure framework is represented in Figure 24. Starting with DEM and topographic and bathymetric maps, subwatersheds were delineated for each of the four modeled areas. Observed precipitation and evaporation data were used as drivers of the SWMM hydrologic model to simulate the runoff hydrograph associated with each of the subwatersheds. Those hydrographs were then linked to the HEC-RAS model along with details of the channel cross-sections and hydraulic structures to route the flow through the channel network. Simulated and observed stage data were compared with respect to three components of the stage hydrograph: maximum stage level, timing of peak, and volume of water. The hydrologic and hydraulic parameters were then tweaked until criteria for achieving a reasonably good calibration were satisfactory. The parameter values were calibrated and validated by adjusting their values and repeating the procedure until the criteria were met. The calibrated model parameters were subsequently used in the design storm analyses.

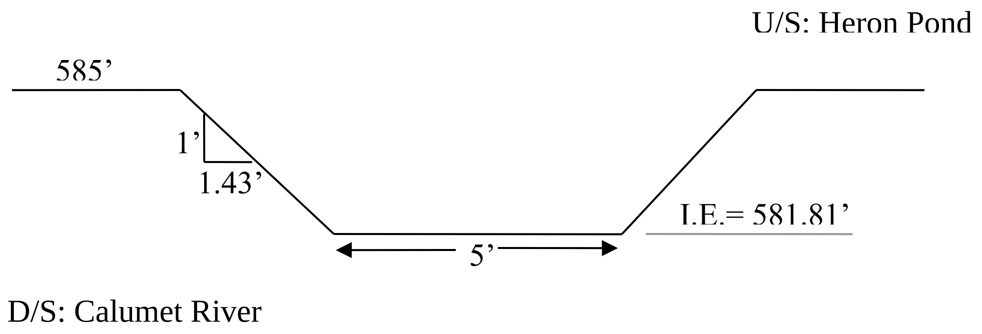

Figure 22. A weir structure connecting the Heron pond to the channel flowing south into the Calumet River (Structure 9).

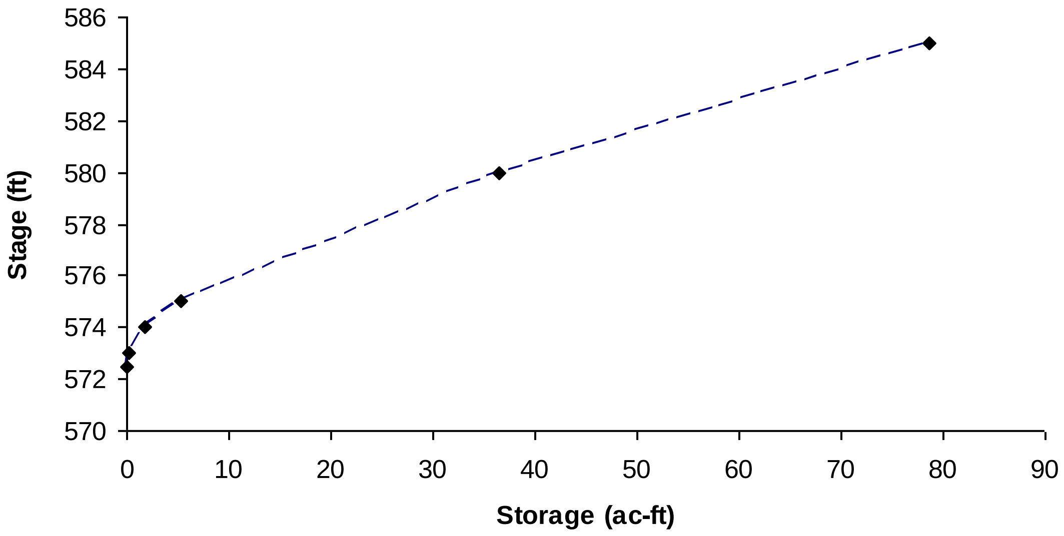

Figure 23. A stage-storage relationship for the Heron Pond.

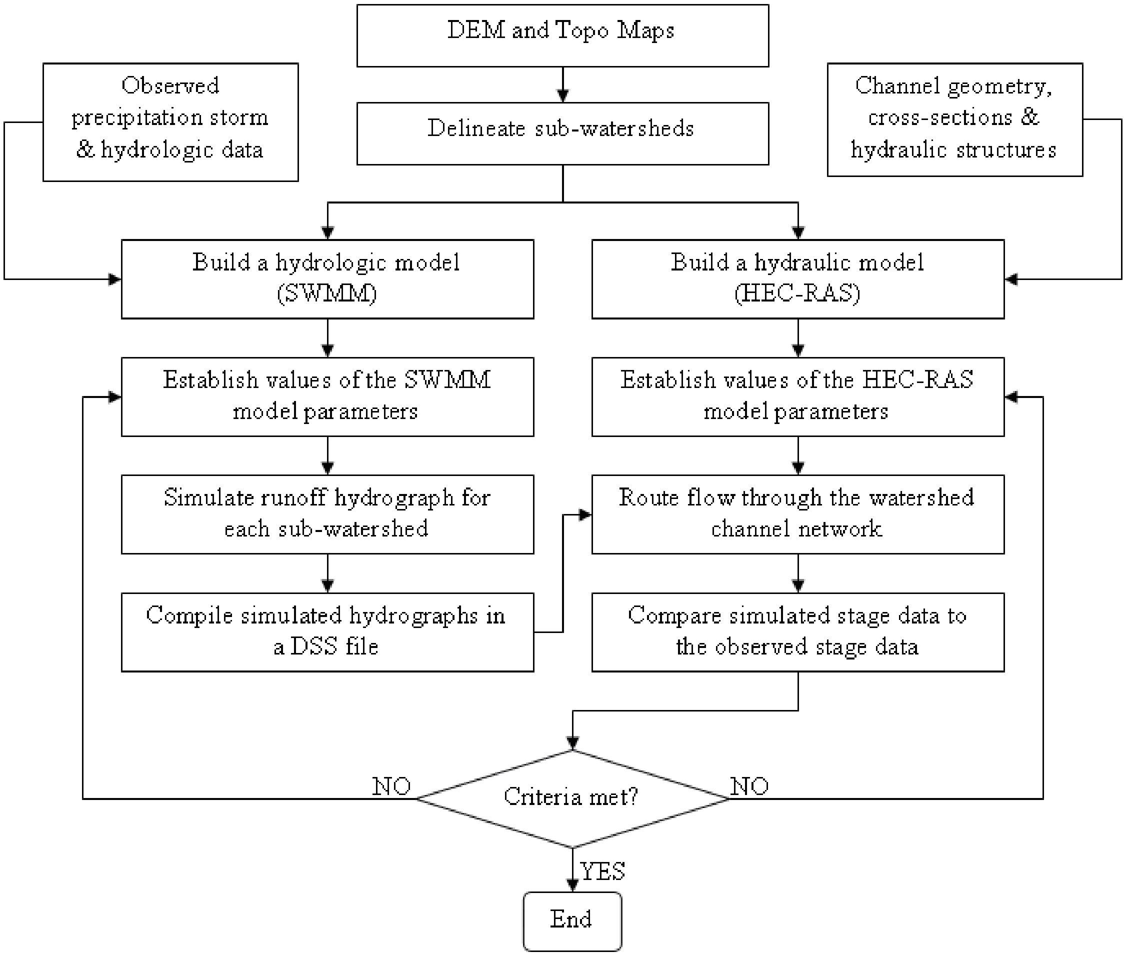

Figure 24. Flowchart of the calibration procedure of both IRM and Big Marsh areas.

Calibration and Validation of Integrated Models

Hourly precipitation data was obtained from the nearest precipitation gage station to the vicinity of the Calumet study area. The selected precipitation gage (ID# 5291) is one of the ISWS monitoring stations and is located in Cook County, southeast of the study area. Precipitation data was provided by Nancy Westcott from ISWS (personal communication). Seven water level monitoring gaging stations were installed in the area, two of them located in the Indian Ridge Marsh stream, two in Big Marsh, two in Dead Stick Pond and one in Heron Pond (Figure 1). Water level data have been collected continuously since 2003 except during some winter seasons when the sensors were unplugged from the gages due to the concerns of equipment damage from icy water.

Two relatively large storms were identified as calibration and validation events. The calibration storm spanned between September 11, 2006 and September 18, 2006 while the validation was based on a storm in July, 2005. The calibration and validation storms were simulated and compared against observed data to ensure the adequacy of the established hydrologic and hydraulic models. It is ideal to use flow hydrographs to calibrate and validate hydrologic models. However, not enough discharge measurements have been collected from the study area, plus a representative rating curve would be hard to develop when beavers modify the height and width of the beaver dam frequently. Hence, due to lack of rating curves at the locations of the gages, the calibration and validation steps were based on the observed stage data instead of observed flow hydrographs. Visual comparison of simulated and observed stage hydrographs at the outlets of IRM and Big Marsh was obtained. Figures 25 through 28 correspond to the visual match of the calibration and validation storm for the IRM and Big Marsh, respectively. The figures show a good overall match between the simulated and observed stage data.

Statistical measures such as coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE) have been used to evaluate the model performance. The Nash-Sutcliffe efficiency (NSE, Nash and Sutcliffe, 1970) was computed as follows:

$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Qobs_i - Qsim_i\right)^2}{\sum_{i=1}^{n}\left(Qobs_i - \overline{Qobs}\right)^2} \qquad (3)$$

where n is the number of discharge values of selected events, $Qsim_i$ and $Qobs_i$ are simulated and observed flows, respectively, and $\overline{Qobs}$ is the average observed flow. When NSE equals to 1, it indicates a perfect fit between simulated and observed data. An NSE value of 0 indicates that the model is predicting no better or no worse than using the average of observed data. Simulation results are considered to be good for values of $NSE \geq 0.75$, but satisfactory for values of NSE between 0.75 and 0.36 (Motovilov et al., 1999).

Statistical measures were also computed from the observed and simulated stages for the IRM and Big Marsh HEC-RAS models and showed the integrated models for the IRM and Big Marsh performed reasonably well for the calibration and validation rainstorm events (Table 3).

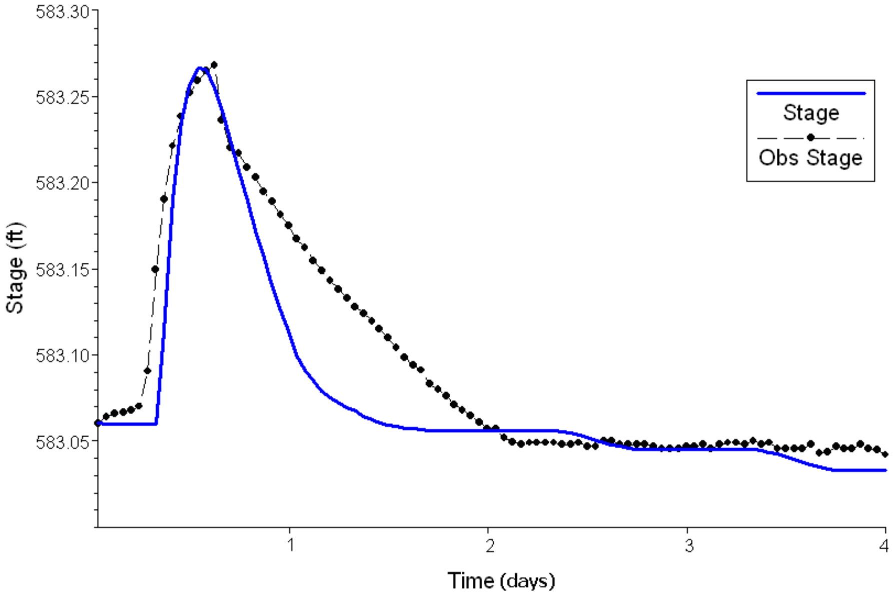

Figure 25. Calibration IRM: Comparison of simulated and observed stage hydrographs at gage ASG4 for the September 11, 2006 rainstorm.

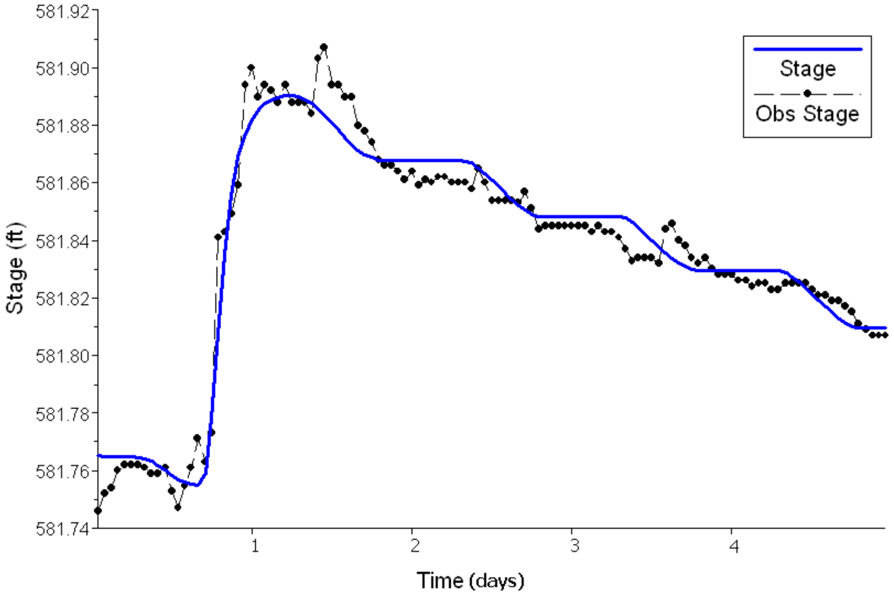

Figure 26. Validation IRM: Comparison of simulated and observed stage hydrographs at gage ASG4 for a July 2005 rainstorm.

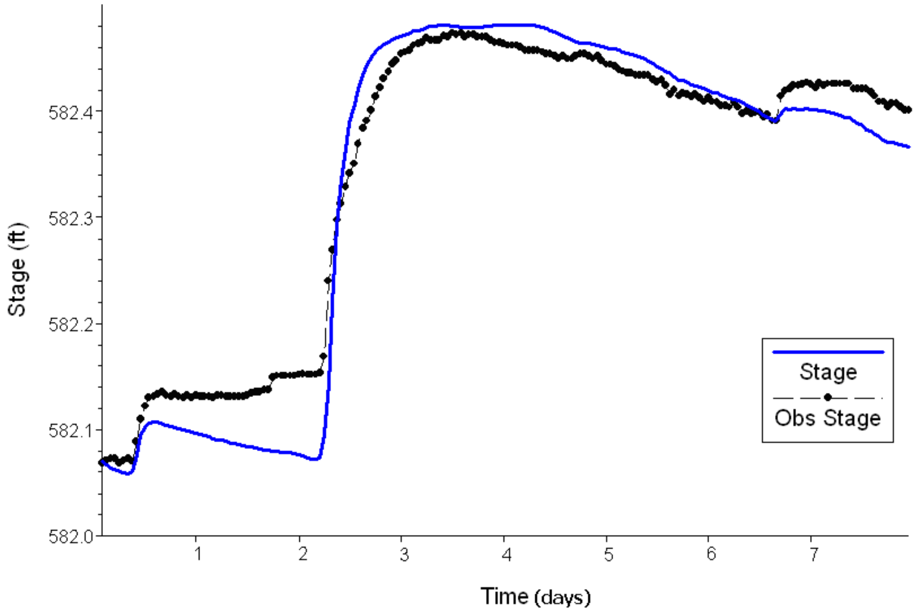

Figure 27. Calibration Big Marsh: Comparison of simulated and observed stage hydrographs at gage ASG2 for the September 11, 2006 rainstorm.

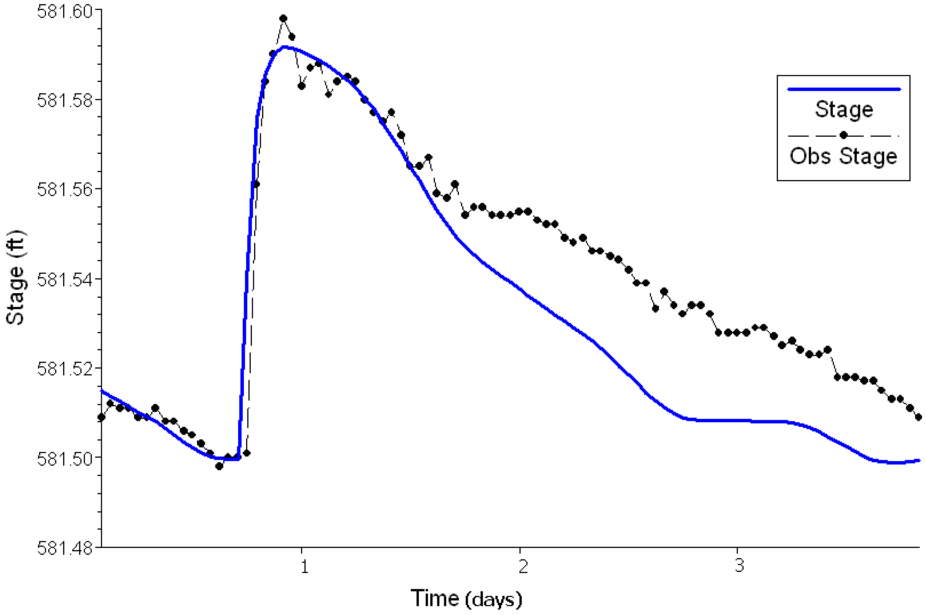

Figure 28. Validation Big Marsh: Comparison of simulated and observed stage hydrographs at gage ASG2 for a July 2005 rainstorm.

Table 3. Statistical Measures Computed from Observed and Simulated Stages.

Modeled Area	Calibration/Validation	R^2	NSE	Figure
IRM	Calibration	0.84	0.77	25
	Validation	0.95	0.95	26
Big Marsh	Calibration	0.88	0.75	27
	Validation	0.87	0.69	28

Discussion

Hydrologic and hydraulic models have been developed for the Indian Ridge Marsh, Big Marsh, Deadstick Pond, and Heron Pond. The HEC-RAS models for Indian Ridge Marsh and Big Marsh were calibrated and validated with historic storm events and can be used to investigate the performance of management and remedial options for storm control, ecosystem restoration, etc. In this study, we employed the hydrologic and hydraulic models to evaluate various management options to control the water level fluctuations in the Indian Ridge Marsh for suitable nesting conditions for Black-Crowned Night-Herons. To do so we first established the critical storm duration (e.g., 3-, 6-, 12-, 24-, 48-, and 96-hour) for each of the 2-, 5-, 10-, 25-, 50-, and 100-year design storm return periods. Once the critical durations were identified, six remedial scenarios were evaluated for each of the return period design storms. Performance of the management scenarios was evaluated in term of achieved reduction in water level fluctuations in the northern pond in IRM.

Design Rainstorms

Traditionally, values for design rainstorms in Illinois are taken from Bulletin 70 (Huff and Angel, 1989). However, the design rainstorm values in this study were based on the NOAA Atlas 14 (Bonnin et al., 2006), because the National Oceanic and Atmospheric Administration (NOAA) completed a more elaborate study using L-moments but based on longer temporal records, much larger spatial coverage, and more sophisticated smoothing techniques to establish design storm magnitudes for different frequencies. Markus et al. (2007) have shown that Bulletin 70 overestimates design storm values when compared to NOAA Atlas 14 or their localized L-Moment approach. The values for the 2-, 5-, 10-, 25-, 50-, and 100-year design rainstorms with durations of 3-, 6-, 12-, 24-, 48-, and 96-hours based on NOAA Atlas 14 are listed in Table 4. The corresponding design storm values for 3-, 6-, 12-, 24-, and 48-hour durations from Bulletin 70 are listed in Table 5. It appeared that the total depth of design rainstorms estimated from Bulletin 70 tend to be higher than from NOAA Atlas 14 across all considered return periods and storm durations.

Table 4. Design precipitation magnitudes based on NOAA Atlas 14 (values in inches).

Storm Return Period	Storm Duration					
	3-hour [1]	6-hour [2]	12-hour [3]	24-hour [4]	48-hour [4]	96-hour [4]
2-year	1.83	2.17	2.49	2.90	3.33	3.73
5-year	2.33	2.80	3.19	3.72	4.21	4.62
10-year	2.72	3.33	3.78	4.40	4.94	5.34
25-year	3.26	4.09	4.62	5.39	5.99	6.36
50-year	3.70	4.75	5.33	6.23	6.87	7.20
100-year	4.15	5.45	6.11	7.14	7.82	8.09

[1]: Huff storm type I; [2]: Huff storm type II; [3]: Huff storm type III; [4]: Huff storm type IV

Table 5. Design precipitation magnitudes based on Bulletin 70 (values in inches).

Storm Return Period	Storm Duration				
	3-hour [1]	6-hour [2]	12-hour [3]	24-hour [4]	48-hour [4]
2-year	1.98	2.33	2.70	3.10	3.35
5-year	2.56	3.00	3.48	4.00	4.32
10-year	2.94	3.45	4.00	4.60	4.97
25-year	3.65	4.28	4.96	5.70	6.16
50-year	4.35	5.10	5.92	6.80	7.34
100-year	4.96	5.81	6.74	7.75	8.37

[1]: Huff storm type I; [2]: Huff storm type II; [3]: Huff storm type III; [4]: Huff storm type IV.

The hyetograph of each design rainstorm was developed based on the Huff distributions presented in Bulletin 70. As proposed by Bulletin 70, storms with durations of 6 hours or less, 6.1 to 12 hours, 12.1 to 24 hours, or greater than 24 hours should be associated with the 1st, 2nd, 3rd, and 4th quartile storm type, respectively.

Critical Storm Duration Analysis

A flowchart of the procedure of establishing the critical storm duration for different return periods of design rainstorms is presented in Figure 29. Initially, the magnitude and distribution of design rainstorms were obtained for different return periods and durations. Then runoffs for different design rainstorms were simulated using the SWMM models for the IRM and Big Marsh areas. Subsequently, runoffs from the contributing watersheds were fed into HEC-RAS models for flow routing in the stream or lake. Because the management study was focused on Black-Crowned Night-Heron nesting in the IRM area, we then computed the maximum fluctuation in stage for each return period (e.g., 2-, 5-, 10-, 25-, 50-, and 100-year) and duration (e.g., 3-, 6-, 12-, 24-, 48-, and 96-hour). To be conservative, the evaluation of each management scenario was based on the most critical storm duration on the system. The most critical storm was defined in term of the maximum induced fluctuation in stage in the IRM northern pond.

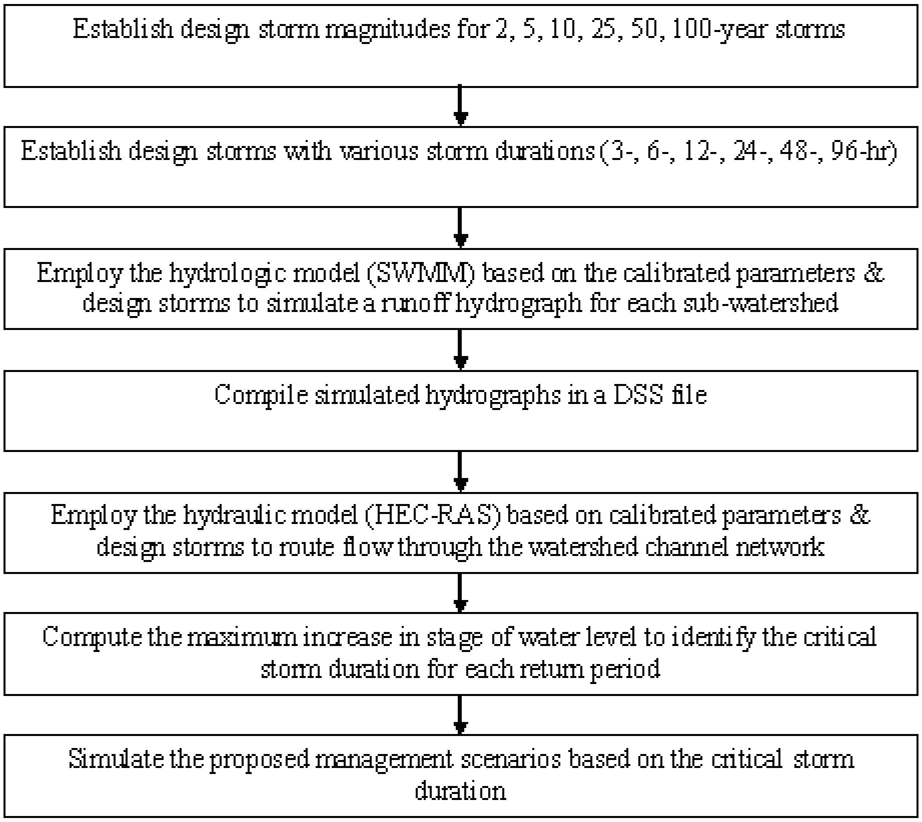

Figure 29. Flowchart of the critical storm analysis and simulation of the proposed management scenarios procedures.

Based on the calibrated hydrologic and hydraulic model parameters, the 36 design storms (Table 4) are simulated using the coupled hydrologic-hydraulic modeling framework for both the IRM and Big Marsh areas. For each return period (e.g., 2-, 5-, 10-, 25-, 50-, and 100-year), the maximum induced changes in stage in the IRM and Big Marsh ponds are summarized in Tables 6 and 7, respectively. The simulations clearly show that the maximum induced change in stage of the IRM and Big Marsh ponds was attained from simulating the 100-year return period and 48-hour duration design storm. This was consistent under shorter return periods only for IRM. Hence, the storm duration of 48 hours (2 days) was considered as the critical design rainstorm.

Table 6. Maximum increase in stage in the IRM pond north of 122nd street and under the various design storms (values in inches); results are based on existing conditions.

Storm Return Period	Storm Duration					
	3-hour	6-hour	12-hour	24-hour	48-hour	96-hour
2-year	0.23	0.71	1.19	2.03	3.23	2.63
5-year	0.95	2.27	3.11	4.55	5.75	4.55
10-year	1.91	3.95	5.03	6.83	7.91	6.23
25-year	3.71	6.71	8.03	10.19	11.15	8.75
50-year	5.15	8.99	10.79	13.07	14.03	10.79
100-year	6.83	11.63	13.67	16.43	17.27	13.31

Table 7. Maximum increase in stage in the southern pond in Big Marsh under the various design storms (values in inches); results are based on existing conditions.

Storm Return Period	Storm Duration					
	3-hour	6-hour	12-hour	24-hour	48-hour	96-hour
2-year	0.72	2.04	3.72	5.28	6.12	**7.20**
5-year	1.56	3.60	5.64	8.16	9.36	**10.32**
10-year	2.40	4.56	7.68	10.44	11.64	**12.60**
25-year	3.60	6.72	10.44	13.44	15.00	**15.60**
50-year	4.32	8.76	12.48	16.20	18.00	**18.36**
100-year	5.04	10.32	14.88	19.32	**21.36**	21.12

Proposed Management Scenarios

Six management scenarios (Table 8) were investigated to establish the most appropriate set of actions to achieve the goals of coping with 100-year critical rainstorm events and providing a safer habitat to the marshes' ecosystem. Jeff Levengood from Illinois Natural History Survey (personal communication) has found that the maximum fluctuation of stage is approximately 10 inches for Night Heron to safely nest in the area. The purpose is to evaluate whether or not these six management scenarios will limit the water level changes to less than the 10-inch target during a 100-year critical rainstorm event.

Slip-lining of the existing culvert under 122nd street (Scenario 1) was thought to be an efficient method to increase the flow capacity through the culvert. This method is appealing because of its ease to implement and relatively low financial obligation. The other approaches require either pumping or installments of additional culverts under 122nd Street which may entail greater construction and maintenance costs.

Table 8. Management Scenarios of the Indian Ridge Marsh.

Management Scenarios	Descriptions
Scenario 1	Slip-lining of existing culvert under 122nd street
Scenario 2	Adding a 2nd culvert next to existing one under 122nd street
Scenario 3	Adding a 2nd culvert on top of existing one under 122nd street
Scenario 4	Removing the two beaver dams
Scenario 5	Diverting flow from Clusters to Big Marsh
Scenario 6	Constructing a storage pond to store flow from Cluster site to later pump into IRM

Scenarios 2 and 3 are to add a second culvert of same size on the side of and on top of the existing one under the 122nd street, respectively. The proposed culvert in Scenario 3 may not reach its full flow capacity under normal condition because of higher invert elevation.

The two beaver dams in the IRM play an important role in controlling the outflow from the marsh area. In scenario 4, we try to investigate the gain in flow capacity and reduction of stage fluctuations from removing these two beaver dams. Rather than increasing the discharge capacity another way of reducing the fluctuation of water surface elevation in IRM is to control the inflow into the area. Scenario 5 assumes that all the runoff generated from Cluster Sites is to be diverted into the northern pond in Big Marsh. Scenario 6 is to control the inflow rate through pumping. This option is to construct a storage pond that has enough storage to store runoff from Cluster Sites for the 100-year critical rainstorm. The stored water can be pumped at a controlled rate into the IRM pond to maintain minimum water level in IRM and also to keep the water in IRM diluted.

Simulation Results and Discussions

Hydrologic and hydraulic models were performed for each of the design rainstorm listed in Table 3. The maximum change in stage in the IRM north were computed from simulations for critical rainstorms and listed in Table 9. Fluctuations of simulated water levels in the northern pond in IRM under the six proposed scenarios (Figure 30) were compared to fluctuations under existing conditions, which had a maximum stage change of 17.27 inches under the 100 year design rainstorm (Table 6).

Table 9. Maximum increase in stage in the IRM pond north of 122nd street and under the various storm return periods and the proposed management scenarios (values in inches).

Storm Return Period	Management Scenarios					
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
2-year	3.71	2.27	2.51	3.00	0.95	0.95
5-year	6.11	4.07	4.43	5.52	1.79	1.79
10-year	8.27	5.75	6.23	7.80	2.51	2.51
25-year	11.75	8.39	8.99	11.16	3.83	3.83
50-year	14.63	10.67	11.39	14.04	4.91	4.91
100-year	17.87	13.31	14.15	17.40	6.23	6.23

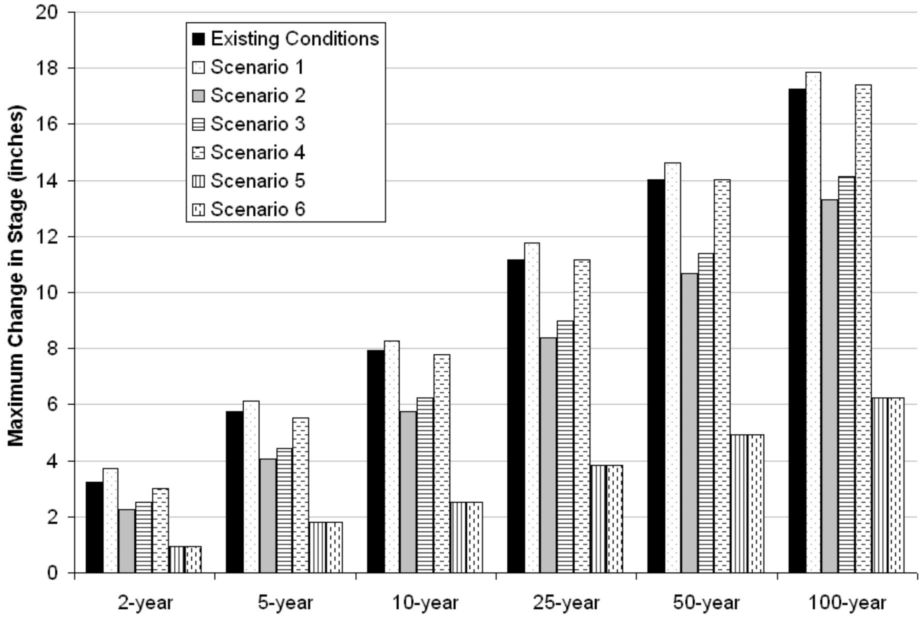

Figure 30. Maximum fluctuation in stage by the 48-hour critical storm and under each of the proposed management scenarios plus existing conditions.

Simulation results show that under Scenario 1, slip-lining actually produced slightly higher peaks than under existing condition (Figure 30). Even though slip-lining provides a smoother wall or smaller Manning's n value, thus less resistance to the flow through the culvert structure, the flow area would be reduced by installing a layer of slip-lining. The combined effect does not increase the flow capacity of the existing culvert. Under Scenarios 2 and 3, reductions from building a second culvert underneath the 122nd street provide some improvement over existing conditions but are insufficient to meet the approximate 10” threshold for the 50- and 100-year return period design storms. Similarly, the option of removing the two beaver dams (Scenario 4) induced minimal improvement of flood drainage condition with the reduction being less than 1 inch from existing conditions for all storm return periods.

Limiting the runoffs from Cluster Sites into IRM as shown in Scenarios 5 and 6 was found to be the most effective scenario to meet the goals of the study. Both scenarios limited the discharge from Cluster Sites to IRM to zero during flood peaks, thus the maximum change in stage value was around 6.23”, which is much less than the 10” of maximum allowable water fluctuation in water level in the IRM pond under the 100-year design storm conditions. The only difference between Scenarios 5 and 6 is in term of handling the diverted runoff from Cluster Sites; thus, their induced maximum stage fluctuations in IRM are equivalent. While Scenario 5 is to divert 100% of the runoff from Cluster Sites to Big Marsh, under Scenario 6, runoff from Cluster Sites is assumed to be stored in a detention pond nearby during rainstorm events. The stored water can be pumped back into the IRM after the end of the storm or during drought seasons not only to maintain the water level but also to improve the water quality in the IRM. The detention pond used in this study was assumed to be 40 ac-ft, enough to store the runoff from Cluster Sites for a 100-year critical rainstorm. The pond was assumed to be 4 ft deep and 10 acres in surface area. A 6-inch pump is assumed and the pumping was assumed to start at the end of the design storm at a rate of 6.68 ft^3/hour and for a duration of 10 hours a day over a four day period to pump a portion of the stored water. Figure 31 shows the simulated stage of the 100-year design storm in IRM northern pond under the Baseline (Existing Conditions) Scenario and Scenario 6. The pumped water induced minimal fluctuations in stage levels.

Runoff from the Cluster Sites under Scenario 5 was used as inflow to the HEC-RAS model for Big Marsh to evaluate the impact on the stage in Big Marsh. The results listed in Table 10 showed that the diverted water from Cluster Sites into Big Marsh northern pond induces a sizable increase in stage peaks of the northern and southern Big Marsh ponds. Under the 100-year return period design storm, the increase in stage in the northern and southern Big Marsh ponds is approximately 22% and 23%, respectively, over the simulated peaks under the existing conditions. Table 11 summarizes the maximum increase in stage in the southern pond in Big Marsh under the six management scenarios for each of the return periods.

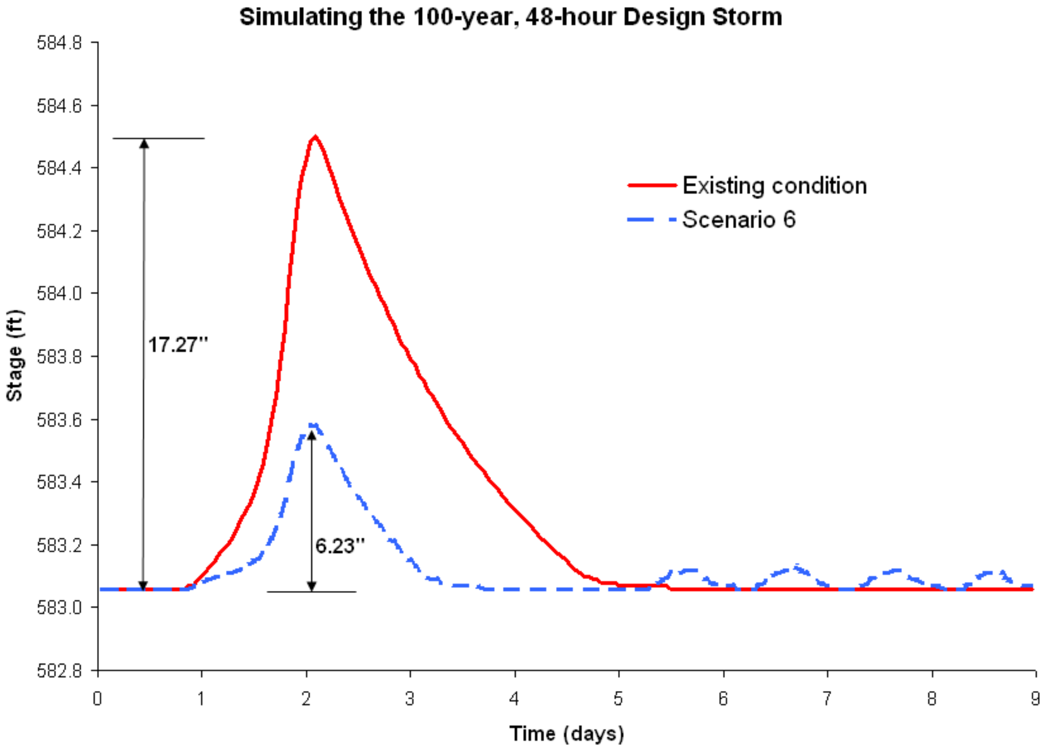

Figure 31. Scenario 6 simulated stage data and compared to baseline scenario.

Table 10. The effect of the diverted water from Clusters site (under Scenario 5) into the northern pond in Big Marsh on maximum stage values; the resulted increase represents the increase in maximum stage over the existing condition scenario (values in inches).

Storm Return Period	Northern Pond			Southern Pond		
	Existing conditions	Scenario 5	Resulted Increase	Existing conditions	Scenario 5	Resulted Increase
2-year	6.12	7.44	1.32	6.12	7.32	1.20
5-year	9.36	11.04	1.68	9.24	11.04	1.80
10-year	11.64	13.80	2.16	11.64	13.80	2.16
25-year	15.00	18.24	3.24	15.00	18.24	3.24
50-year	18.00	22.08	4.08	18.12	21.96	3.84
100-year	21.36	26.16	4.80	21.24	26.16	4.92

Table 11. Maximum increase in stage in the southern pond in Big Marsh under the various storm return periods and the proposed management scenarios (values in inches).

Storm Return Period	Management Scenarios					
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
2-year	6.12	6.12	6.12	6.12	7.32	6.12
5-year	9.36	9.36	9.36	9.36	11.04	9.36
10-year	11.64	11.64	11.64	11.64	13.80	11.64
25-year	15.00	15.00	15.00	15.00	18.24	15.00
50-year	18.00	18.00	18.00	18.00	21.96	18.00
100-year	21.36	21.36	21.36	21.36	26.16	21.36

Post-Capping Conditions

In an effort to reduce infiltration into contaminated soils in the Cluster Sites, the City of Chicago capped the Calumet Cluster Landfill with clay in 2007. Because no rainfall-stage data exist based on the post-capping conditions, the established hydrologic and hydraulic models were not directly used to determine the capping impact on runoff and stage fluctuation. Ecology and Environment, Inc. (E&E) calculated runoff from the capped area under the 25-, and 100-year, 24-hour design rainfall event. Their model employs the Santa Barbara Unit Hydrograph (SBUH) method. Infiltration and storage losses were estimated using the NRCS method.

In order to evaluate the impact of capping the Cluster Landfill to the water level fluctuation in the IRM, we employed the rainfall-runoff calculation method used by E&E. However, the rainfall depths and distribution for the 25- and 100-year design rainstorms were based on the NOAA Atlas 14 estimates and the Huff distribution instead of the ad hoc rainfall distribution used by E&E. Runoffs from the Cluster Landfill site were estimated for capping condition and were fed into the HEC-RAS model to perform flow routing. Runoffs from other contributing subwatersheds of the IRM remained the same. The simulation results showed that the construction of the impervious cap is estimated to increase surface runoff from Cluster Landfill by 19.9% (from 19.14 to 22.96 cfs) and 14.8% (from 28.68 to 32.94 cfs) under the 25- and 100-year, 24-hour design storms, respectively. Those changes translate into a minimal change in the stage fluctuation in IRM upstream of 122nd street. Table 12 showed that going from pre- to post-capping conditions, the peak stage upstream from 122nd street increases slightly from 583.91’ and 584.43’ to 583.97’ and 584.50’ for the 25- and 100-year design storms, respectively.

Table 12. The difference in maximum stage and flow conditions prior and after the proposed capping scenario of the Cluster Landfill Site.

Capping Status	100-year		25-year	
	Maximum Stage (ft)	Maximum Flow (cfs)	Maximum Stage (ft)	Maximum Flow (cfs)
Pre-capped	584.43	13.81	583.91	11.12
Post-capped	584.50	14.10	583.97	11.54
Difference	0.07	0.29	0.06	0.42

Conclusion

To support the development plan for the Calumet region to become an ecological park, the ISWS has developed an integrated SWMM and HEC-RAS model for the north and south IRM areas and the Cluster Sites. The integrated model was calibrated and validated with observed rainstorms events. We have found that 48-hour is the critical duration for 100-year rainstorm to produce the largest water level fluctuations in the north IRM area. This report presented the results from evaluating six management scenarios to cope with flooding and to establish a more suitable environment for the Night Heron nests in the marsh areas through controlling the water level fluctuations.

It is apparent that the culvert underneath the 122nd street between the north and south IRM is the bottleneck for flood drainage. Scenarios 1 to 4 were to improve the flow capacity through this culvert. Simulations show that slip-lining of culvert would have minimal improvement of flow condition. The reduction of stage fluctuations from existing condition is less than one inch. It also showed that the bottleneck effect of the 122nd street remains even when both beaver dams were removed. The reduction of fluctuation would only be about two inches. Even though adding another culvert either on top of or next to the existing culvert would have more reduction of stage fluctuation, the total fluctuations still exceed the target of less than 10 inches. As shown in Scenario 5, the target is achieved by diverting all the runoff from Cluster Sites to an adjacent area, namely Big Marsh. However, limiting clean surface runoff from the Cluster Sites to IRM would result in worse water quality in the IRM stream. The clean surface runoff from the Cluster Sites would help to dilute and slush the stagnant water in the IRM stream. Thus, the impact of eliminating surface runoff from Cluster Sites needs to be further evaluated.

In order to minimize water level fluctuations and at the same time to use the clean water from the Cluster Sites to mitigate the water quality of the IRM water body, a pumping scenario was adopted in Scenario 6. The pumping option proposed designing a detention pond that has enough capacity to store 100-year storm runoff from the Cluster Sites so the stage fluctuation in IRM stream can meet the target during the rainstorm event. The stored clean water was pumped into the IRM stream after the rainstorm had stopped and stage levels dropped back to base flow level. This scenario successfully met the objective by reducing the water level fluctuation in the IRM below the 10” target. Scenario 6 also merits the potential to alleviate current and future water quality concerns in the marshes. The water quality of IRM and the impact of groundwater to the IRM will be further investigated in another two-year Indiana-Illinois Sea Grant project.

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