1. Introduction

The North Branch Chicago River and Lake Michigan watersheds, located in northeastern Cook County, Illinois, drain an area of over 120 square miles that includes 20 communities. Figure ES.1 shows an overview of the North Branch Chicago River (NBCR) and Lake Michigan (LM) watersheds.

The NBCR watershed is a heavily urbanized area with small portions of forest preserve and park areas, and is generally characterized by low relief. The headwaters of the three major tributaries, the Skokie River, the Middle Fork, and the West Fork, are located in Lake County, IL. These tributaries flow south into Cook County at Lake Cook Road and combine with the Main Stem of the NBCR at Beckwith Road within Chick Evans golf course. Another tributary, the North Shore Channel (NSC), enters the Main Stem of the NBCR near Albany Avenue in Chicago, adjacent to the North Branch Dam at Albany Park. The downstream limit of the NBCR is at the confluence with the Chicago River and South Branch of the Chicago River near W. Lake Street in downtown Chicago. Locations of historic flooding mainly exist on the West Fork, the Skokie River and the NBCR, and upstream of the North Branch Dam; while locations of streambank erosion exist primarily on the West Fork, Middle Fork, and Main Steam of the NBCR upstream of the North Branch Dam.

The Lake Michigan watershed within Cook County is located along the west coast of Lake Michigan and generally extends west to the topographic ridge along Green Bay Road. The Lake Michigan watershed consists of seven ravines which drain east into Lake Michigan. The Lake Michigan watershed shows no signs of historic flooding problems or signs of streambank erosion. Soil erosion does occur along the bluffs of the Lake Michigan shoreline and, to a lesser extent, along the ravines. However, this DWP does not address bluff/ravine erosion, but rather active erosion along regional waterways that pose an imminent risk to structures or critical infrastructure and / or threaten public safety.

The NBCR and Lake Michigan Detailed Watershed Plan (DWP) was developed by the Metropolitan Water Reclamation District of Greater Chicago (District) with the participation of the NBCR Watershed Planning Council (WPC) which provided local input to the District throughout the development process. The DWP was developed to accomplish the following goals:

- Document stormwater problem areas.
- Evaluate existing watershed conditions using hydrologic and hydraulic (H&H) models.
- Produce flow, stage, frequency, and duration information along regional waterways.
- Estimate damages associated with regional stormwater problems.
- Evaluate solutions to regional stormwater problems.

Regional problems are defined as problems associated with waterways whose watersheds encompass multiple jurisdictions and drain an area greater than 0.5 square miles. Problems arising from capacity issues on local systems, such as storm sewer systems and minor open channel ditches, even if they drain more than one municipality, were considered local and beyond the scope of this regional stormwater management program. Erosion problems addressed in this plan were limited to active erosion along regional waterways that pose an imminent risk to structures or critical infrastructure and/or threaten public safety. Interstate highways, U.S. highways, state routes, county roads with four or more lanes, and smaller roads providing critical access that are impacted by overbank flooding of regional waterways at depths exceeding 0.5 feet were also considered regional problems.

1.1 Scope and Approach

The DWP scope included data collection and evaluation, H&H modeling, development and evaluation of alternatives, and recommendation of alternatives. The data collection and evaluation task included collection and evaluation of existing H&H models, geospatial data, previous studies, reported problem areas, and other data relevant to the watershed plan. H&H models were developed to produce inundation mapping for existing conditions for the 100-year storm event and to evaluate stormwater improvement project alternatives. Stormwater improvement project alternatives were developed and evaluated to determine their effectiveness in addressing regional stormwater problems. Estimates of damage reduction, or benefits, associated with proposed projects were considered along with conceptual cost estimates and noneconomic criteria to develop a list of recommended improvement projects for the NBCR and Lake Michigan watersheds.

1.2 Data Collection and Evaluation

The data collection and evaluation phase (Phase A) of the DWP focused on obtaining data regarding the watershed and evaluation of the material's acceptability for use. The District contacted all WPC members as well as federal and state agencies and other stakeholders requesting relevant data. Coordination with WPC members took place throughout development of the DWP. Existing and newly developed data was evaluated according to criteria of use defined in Chapter 6 of the *Cook County Stormwater Management Plan* (CCSMP), included in Appendix B. Where data was unavailable or insufficient to complete the DWP, additional data was collected. This report includes information on all data collected and evaluated as a part of the DWP development. Table 1.2.1 lists key dates of coordination activities including meetings with WPC members throughout DWP development.

1.3 Hydrologic and Hydraulic Modeling

This section of the report provides a description of H&H modeling completed to support the DWP development. H&H models were developed for all tributaries within the watershed containing open waterways. Most models were developed independently of any past H&H modeling efforts. There were several locations, however, where existing models or studies were used. For the Techny Drain tributary, a hydrologic study was used to assist with subbasin delineation and flow diversion modeling. For the Underwriter's Tributary, a hydrologic and hydraulic study was used to assist with subbasin delineation and storage modeling. Data from existing regulatory hydraulic models was used for supplementing the newly developed DWP HEC-RAS hydraulic models for the West Fork, Middle Fork, Skokie River and Main Stem of the NBCR. The United States Army Corps of Engineers's (USACE's) recent hydraulic model of the Chicago Area Waterway System (CAWS) was used to develop the water surface profiles of the North Shore Channel and the Main Stem of the NBCR downstream of the North Branch Dam.

Although hydraulic model extent was defined based upon the extent of detailed study for effective Digital Flood Insurance Rate Maps (DFIRMs), models were extended further, where appropriate, to aid evaluation of damages associated with regional stormwater problems. Appendix A includes a comparison of FEMA's revised DFIRM panels with inundation areas developed for DWP modeling purposes. Tables comparing DWP inundation area to FEMA floodplain mapping by community and subwatershed are also included in Appendix A.

H&H models were developed to be consistent with the protocols defined in Chapter 6 of the CCSMP. In numerous instances, models included additional open channel or other drainage facilities not strictly required by Chapter 6, to aid the evaluation of community reported problem areas. Available monitoring data, including USGS stream gage data, District facility data and high water marks observed following storm events were used to perform model verification and calibration consistent with Chapter 6 guidelines. All H&H modeling data and documentation of the data development are included in the appendices referenced in the report sections below.

TABLE 1.3.1
WPC Coordination Activities

Description of Activity		**Date**
07-029-5C NBCR and Lake Michigan Detailed Watershed Plan - Phase A - Contract start date		January 15, 2008
08-033-5C NBCR and Lake Michigan Detailed Watershed Plan - Phase B - Contract start date		September 11, 2008
Information Gathering		
Data Request (Forms A and B) sent out as part of Phase A		August 17, 2007
Watershed field visit and meetings with various municipalities		September 2008 to September 2010
Open meetings with Watershed representatives during Phase A to discuss Forms A and B		January 30, 2008
District phone calls and emails to communities after the September 13th and 14th, 2008 storm event		September 2008
NBCR and Lake Michigan Watershed Planning Council Meetings (20)		
October 26, 2005	March 7, 2006	June 6, 2006
September 5, 2006	December 5, 2006	March 6, 2007
June 5, 2007	September 4, 2007	December 4, 2007
March 4, 2008	June 3, 2008	September 2, 2008
December 2, 2008	March 3, 2009	June 2, 2009
September 1, 2009	December 1, 2009	March 2, 2010
June 1, 2010	September 7, 2010	

TABLE 1.3.1
WPC Coordination Activities

Modeling Results and Alternatives Review Meetings		
Initial Model Review Workshop		September 17, 2009 and May 20, 2010
Preliminary Alternatives Review Workshop		June 29, 2010
Final Alternatives Presentation Workshop		August 12, 2010
MWRDGC Board of Commissioners' Study Sessions		
January 10, 2006	April 27, 2006	October 2, 2008

1.3.1 Model Selection

H&H models were developed within the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) Version 3.1.0 modeling application and Hydrologic Engineering Center-River Analysis System (HEC-RAS) Version 4.0. These applications were identified as acceptable in Tables 6.10 and 6.11 of the CCSMP. The Soil Conservation Service (SCS) curve number (CN) loss module was used with the Clark's unit hydrograph methodology within HEC-HMS to model basin hydrology. The dynamic unsteady flow routing methodology was used within HEC-RAS. Both applications have an extensive toolkit to interface with geographic information systems (GIS) software to produce input data and display model results.

1.3.2 Model Setup and Unit Numbering

1.3.2.1 Hydrologic Model Setup

Hydrologic model data was primarily developed within the GeoHMS (Version 4.2) extension to Arc GIS Version 9.3.1. The extension provides an interface to geoprocessing functions used to characterize subbasin parameters within the hydrologic model. GeoHMS was used to calculate the CN for each basin; to define the longest flow path, basin slope, and longest flow path slope; and to establish a network connecting hydrologic elements (e.g., subbasins, reservoirs, reaches, and inflow locations) to the outlet of the system. HEC-HMS was used to create and sometimes route stormwater runoff hydrographs to the upstream extent of hydraulic models developed within HEC-RAS. Hydrologic model data was transferred between HEC-HMS and HEC-RAS through HEC-DSS files.

Subbasin Delineation. Within Cook County, each major tributary model (West Fork, Middle Fork, Skokie River, etc.) was divided into subbasins roughly 320 acres (0.5 square miles) in size to form the basis of the hydrologic model and was modeled assuming a unified response to rainfall based on land use characteristics and soil type. Elevation data provided by Cook County, described in Section 2.3.4, was the principal data source used for subbasin delineation. Drainage divides were established based upon consideration of the direction of steepest descent from local elevation maxima, and refined in some instances to reflect modifications to topographic drainage patterns caused by stormwater management infrastructure (storm sewer systems, culverts, etc.). Subbasin boundaries were modified to encompass areas with similar development patterns. Finally, boundaries were defined to most accurately represent the area tributary to specific modeled elements, such as constrictions caused by crossings, and reservoirs. GIS data was developed for all subbasins delineated and used for hydrologic model data development. In the upper extents of the watershed, within Lake County, a more generalized delineation approach with the USGS's 10 meter National Elevation Dataset (NED) was used for contouring, and basins were delineated to a size of approximately one square mile.

Runoff Volume Calculation. The SCS CN loss model uses the empirical CN parameter to calculate runoff volumes based on landscape characteristics such as soil type, land cover, imperviousness, and land use development. *Areas characterized by saturated or poorly infiltrating soils, or impervious development, have higher CN values, converting a greater portion of rainfall volume into runoff. The SCS methodology uses Equation 1.1 to compute stormwater runoff volume for each time step:*

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1.1)$$

Where:

Q = runoff volume (in.)
P = precipitation (in.)
S = storage coefficient (in.)
I_a = initial abstractions (in.)

Rainfall abstractions due to ponding and evapotranspiration can be simulated using an initial abstractions (I_a) parameter. In the NBCR DWP, the commonly used default value of I_a, estimated as 0.2 × S, where S is the storage coefficient for soil in the subbasin. S is related to CN through Equation 1.2:

$$S = \frac{1000}{CN} - 10 \qquad (1.2)$$

where:

CN = curve number (dimensionless)
S = storage coefficient (in,)

Table 1.3.2 describes the input data used to develop the CN values throughout the watershed.

TABLE 1.3.2
Description of Curve Number Input Data

Variable Used to Determine CN	Approach for Definition of Variable for NBCR and Lake Michigan Watershed Hydrologic Modeling
Ground cover	Chicago Metropolitan Agency for Planning (CMAP) 2001 land use inventory (v.1.2 2006) is used to define land use. A lookup table was developed to link CMAP categories to categories for which CN values have been estimated.

TABLE 1.3.2
Description of Curve Number Input Data

Variable Used to Determine CN	Approach for Definition of Variable for NBCR and Lake Michigan Watershed Hydrologic Modeling
Soil type	The Natural Resources Conservation Service (NRCS) publishes county soil surveys that cover portions of the watershed except areas within the City of Chicago and other lower basin areas. The NRCS surveys include a hydrologic classification of A, B, C, or D. Generally a soil classification of A will represent soils with the highest infiltration potential, whereas a classification of D will represent the lowest infiltration potential. If a soil group's infiltration capacity is affected by a high water table, it is classified as, for instance, "A/D," meaning the drained soil has "A" infiltration characteristics, undrained "D." It was assumed that half of these soil groups (by area) are drained. Soil types outside of the NRCS soil survey areas were determined through use of the NRCS's STATSGO dataset. It was assumed that half of the STATSGO soil groups, by area, are drained.
Antecedent moisture condition	Antecedent Moisture Conditions (AMC) reflects the initial soil storage capacity available for rainfall. For areas within Northeastern Illinois, it is typical to assume an AMC of II.

Specific combinations of land use and soil type were linked to CN values using a lookup table based on values recommended in Table 1.3.3 excerpted from *TR-55: Urban Hydrology for Small Watersheds* (U.S. Department of Agriculture [USDA], 1986). The CN matrix includes assumptions about the imperviousness of land use classes, and therefore, percent impervious does not need to be explicitly considered as the SCS runoff volume calculation. Since the CMAP land-use data does not correspond to the categories in Table 1.3.3, development of a mapping process between TR-55 land use categories and CMAP land use categories was necessary. This process is detailed in Appendix C, which includes a technical memorandum detailing the process used to develop CN values for the NBCR watershed and Lake Michigan watershed.

The GeoHMS tool was used to develop an area-weighted average CN for each subbasin.

Runoff Hydrograph Production.

The runoff volume produced for a subbasin is converted into a basin-specific hydrograph by using a standard unit hydrograph and an estimate of subbasin time of concentration. The standard unit hydrograph method used for the NBCR watershed was the Clark unit hydrograph method, and the SCS unit hydrograph method was used for the Lake Michigan Watershed. Estimates of subbasin time of concentration values were performed using SCS methodologies.

The time of concentration is the time it takes for a drop of water to travel from the hydraulically furthest point in a watershed to the outlet. Using SCS methodologies, the time of concentration is estimated as the sum of the travel time for three different segments of flow, split-up by flow type in each subbasin.

TABLE 1.3.3
Runoff Curve Numbers for Urban Areas

Cover Type and Hydrologic Condition	Avg. % Impervious Area	A	B	C	D
Fully developed urban areas (vegetation established)					
Open Space (lawns, parks, golf courses, cemeteries, etc.)					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50 to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious Areas					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western Desert Urban Areas					
Natural desert landscaping (pervious areas only)		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin barriers		96	96	96	96
Urban Districts					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential Districts by Average Lot Size					
1/8 acre or less	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing Urban Areas					
Newly Graded Areas (pervious areas only, no vegetation)		77	86	91	94

Note: Average runoff condition, and $I_a = 0.2S$.

Note: Source of table is *TR-55: Urban Hydrology for Small Watersheds* (U.S. Department of Agriculture [USDA], 1986)

Thus Equation 1.3:

$$T_c = T_{sheet} + T_{shallow} + T_{channel} \qquad (1.3)$$

where:

T_{sheet} = sheet flow; flow occurring across the land area headwater areas prior to flow accumulation

$T_{shallow}$ = shallow flow; occurs where sheet flow begins to accumulate into more concentrated patterns, but prior to transitioning into open channel flow

$T_{channel}$ = flow within natural or manmade drainage facilities within each subwatershed prior to the point of discharge

GeoHMS was used to determine the route of the longest flow path, and that flow path's length and slope. The basin parameter estimates were exported to a spreadsheet to support calculation of T_c.

Comparison of HEC-HMS results to gage data was initially performed using the Clark Method and SCS Method unit hydrographs. This comparison evaluation indicated that the Clark Method unit hydrographs produced more representative results for the North Branch of the Chicago River, West Fork, Middle Fork, and Skokie River subwatersheds.

The storage coefficient for the Clark methodology was estimated using equation 1.4.

$$\frac{R}{Tc + R} = C \qquad (1.4)$$

The value for C was determined using USGS Water Resources Investigation Report 00-4184. The value for C and estimated subbasin Tc values were used to calculate R values for each subbasin. The values of Tc originally calculated appeared reasonable based on the topography of the subbasins, and subsequent review of hydrograph comparisons confirmed that overall timing of the watershed as indicated by the model was representative of actual conditions.

As described above, the Clark unit hydrograph method was used for the NBCR Watershed; however, the SCS unit hydrograph method was used for the Lake Michigan Watershed. Due to the steepness of terrain and relative lack of channel storage in the Lake Michigan Watershed, the SCS unit hydrograph method was more applicable and provided more reasonable results. The SCS unit hydrograph method converts the runoff volume produced for a specific subbasin into a basin specific hydrograph using a standard SCS unit hydrograph and an estimate of subbasin lag time. The lag time is defined as the time elapsed between the mass centroid of precipitation and peak of the runoff hydrograph at the outlet of the subbasin. Lag times for the Lake Michigan watershed were estimated according to Equation 1.5, provided in the HEC-HMS Technical Reference Manual (USACE, 2006):

$$T_{lag} = 0.6T_c \qquad (1.5)$$

where:

T_{lag} = Lag time

T_c = Time of Concentration

Time of concentration estimates for the Lake Michigan Watershed were performed using the same SCS method described in the text above and Equation 1.3.

Rainfall Data. Observed and design event rainfall data was used to support modeling evaluations for the DWP. Monitored rainfall data is described in Section 2.3.1. Design event rainfall data was obtained from Bulletin 71, *Rainfall Frequency Atlas of the Midwest* (Huff, 1992). Design event rainfall depths obtained from Bulletin 71 were used to support design event modeling performed for existing and proposed conditions assessment.

1.3.3 Storm Duration

A critical-duration analysis was performed to determine the storm duration that generally results in higher water surface estimates for a range of tributary sizes within the NBCR watershed. The 24-hour duration storm was identified as the critical duration for streams within the NBCR watershed. A third quartile storm is recommended for storms of this duration (Huff, 1992). Table 1.3.4 summarizes rainfall depths for the 24-hour duration storm.

1.3.4 Areal Reduction Factor

The rainfall depths presented in Table 1.3.4 summarize expected point rainfall accumulation for modeled recurrence intervals. The probability of uniform rainfall across a subwatershed decreases with increasing watershed size. Table 21 of Bulletin 71 relates areal mean rainfall depth to rainfall depth at a point (Huff, 1992). After review of subwatershed (West Fork, Middle Fork, Skokie River, and Main Stem of the NBCR) sizes, and modeling sensitivity, it was determined that a reduction factor is not appropriate within the NBCR watershed. Bulletin 71 also provides rainfall distributions that vary according to watershed size (point distribution, 10 to 50 square mile area, 50 to 100 square mile, etc). The rainfall distribution used was a point distribution in order to provide more accurate results for smaller tributaries and the upper portion of the watershed. Review of modeling sensitivity indicates that use of the 10 to 50 square mile area distribution results in insignificant changes to peak flow rates within the watersheds main stream reaches.

TABLE 1.3.4
Rainfall Depths

Recurrence Interval	24-hr Duration Rainfall Depth
2-year	3.04
5-year	3.80
10-year	4.47
25- year	5.51
50- year	6.46
100-year	7.58
500-year	10.90[a]

[a] 500-year rainfall depth was determined based on a logarithmic relationship between rainfall depth and recurrence interval.

1.3.5 Hydrologic Routing

Stormwater runoff hydrographs were routed within HEC-HMS in upstream areas where the resolution of subbasins defined was greater than the hydraulic model extent. In areas where a channel cross section could be identified from topographic data, Muskingum-Cunge routing was performed using the approximate channel geometry from a representative cross section of the modeled hydrologic reach. To account for reach storage effects, lateral inflow hydrographs produced within HEC-HMS, were input to the HEC-RAS unsteady-state hydraulic model. For the portions of the Middle Fork and Skokie River within Lake County, modified puls storage-discharge relationships from the existing hydrologic models (effective FIS models) were incorporated into the new HEC-HMS modeling developed for this DWP.

1.3.6 Hydraulic Model Setup

Hydraulic model data was typically developed through field surveys with some additional definition of channel overbank areas and roadway crests defined using Cook County 2003 topographic LiDAR data. Cross section locations were developed in HEC GeoRAS, and surveyed channel geometry was inserted into topographically generated cross sectional data. Cross sections were generally surveyed at intervals of 500 to 1,000 feet. Interpolated cross sections were added at many locations to the models to increase stability and reduce errors. Bridges, culverts, and other major hydraulic structures were surveyed within the hydraulic model extent. The locations of all surveyed and modeled cross sections, bridges, culverts, and other structures are shown in Appendix D.

1.3.6.1 Bridges, Culverts, and Hydraulic Structures

Bridges, culverts, and hydraulic structures were surveyed consistent with FEMA mapping protocol as identified in *Guidelines and Specifications for Flood Hazard Mapping Partners*, "Guidance for Aerial Mapping and Surveying" (FEMA 2003). A State of Illinois licensed professional land surveyor certified each location as FEMA compliant. Documentation of certifications is provided in Appendix D. Bridges, culverts, and hydraulic structures were surveyed consistent with the NAVD 1988 datum using 5-centimeter or better GPS procedures (as specified in NGS-58 for local network accuracy) or third-order (or better) differential leveling, or trigonometric leveling for short distances. In a few cases, information from construction as-built plans was used in lieu of surveying. Ineffective flow areas were placed at cross sections upstream and downstream of crossings, assuming a contraction ratio of 1:1 and an expansion ratio of 2:1. Contraction and expansion coefficients generally were increased to 0.3 and 0.5, respectively, at cross sections adjacent to crossings and in areas where severe meandering occurred along the reach.

1.3.6.2 Cross-Sectional Data

Cross-sectional data was surveyed consistent with FEMA mapping protocol as identified in *Guidelines and Specifications for Flood Hazard Mapping Partners*, "Guidance for Aerial Mapping and Surveying" (FEMA 2003).

All survey work, including survey of cross sections, was certified as compliant to FEMA mapping protocol by a licensed professional land surveyor. Documentation of certifications is provided in Appendix D. Cross sections were surveyed consistent with the North American Vertical Datum, 1988 (NAVD 1988) using 5-centimeter or better GPS procedures (as specified in NGS-58 for local network accuracy) or third-order (or better) differential leveling, or trigonometric leveling for short distances. Cross sections were interpolated at many locations within the hydraulic models, to aid model stability and reduce errors.

1.3.6.3 Boundary Conditions

The perimeter of District jurisdiction, watershed geographic considerations, and modeling methodologies were used to determine the appropriate boundary conditions for hydraulic modeling.

The USACE's model of the CAWS provided tailwater conditions for the hydraulic models upstream of the North Branch Dam within the Main Stem of the NBCR.

Within the Lake Michigan watershed, a downstream boundary condition was only required for Ravine 1 since this was the only Ravine modeled within the study. Due to the relatively steep nature of the ravine that generates supercritical flows; downstream water surface elevations did not have significant backwater effects on the upstream portions of the ravine. For this reason, the hydraulic analysis of Ravine 1 assumed critical flow depth at the downstream end of the hydraulic model.

1.3.7 Model Run Settings

All hydraulic model simulations were carried out using the fully dynamic, unsteady flow simulation settings within HEC-RAS. The Saint-Venant equations, or the continuity and momentum balance equations for open channel flow, were solved using implicit finite difference scheme. HEC-RAS has the ability to model storage areas and hydraulic connections between storage areas and between stream reaches. The computational time step for model runs was generally 15 seconds.

1.3.8 Model Calibration and Verification

The hydrologic and hydraulic models developed for the DWP were calibrated and verified in order to create modeling that is representative of watershed stormwater runoff response for a range of storm magnitudes. Calibration, as used in this DWP, is to be defined as the adjustment of modeling parameters to cause a model to be more representative of recorded data. Verification, as used in this DWP, refers to running a model using an independent storm event and checking that the results produced are representative of recorded data. In the case of this DWP, the September 13-14, 2008 storm event was used as the basis for calibration. The October 14-16, 2001 storm event was used for verification.

Output from the HEC-HMS hydrologic model was used as input to the HEC-RAS hydraulic model. Within the DWP project area (south of the Cook-Lake County line), the hydrologic model used Muskingum Cunge channel routing which does not take into account the flow attenuation that occurs in the channel and overbank areas. Attenuation was accounted for in the unsteady HEC-RAS model. As a result, adjustments to the HEC-HMS model, for purposes of calibration, could only be made after comparison of HEC-RAS hydrographs to river gage hydrographs. This comparison was performed at the Main Stem river gage location in the community of Niles and it was determined that the HEC-HMS model was providing representative lateral hydrograph inputs for both the 2008 and 2001 storm events. Peak runoff rates and volumes were within 30% as required by District criteria. Detailed calibration results are presented in subwatershed subsections, including hydrographs and comparisons of stage and runoff volume.

Approximately 40% of the NBCR watershed area is located north of the DWP project area (north of the Lake-Cook County line). Although HEC-1 modeling existed for this area, the HEC-HMS model created for the DWP was extended northward to include this area. For the Middle Fork and Skokie River, modified puls data from the HEC-1 models was incorporated into the HEC-HMS models, and modeling parameter adjustments (Curve Number and storage coefficient) were made to make the HEC-HMS model representative of existing land use conditions. Evaluation of HEC-1, HEC-HMS, and river gage hydrographs at the county line indicated that the HEC-HMS produced hydrographs were appropriate for use as a boundary condition for the Middle Fork and Skokie River. Due to the locations of existing gages and the presence of the Deerfield Reservoir near the county line, the HEC-1 hydrograph for the West Fork was used as a boundary condition.

Water surface elevation output from the 2008 HEC-RAS model were compared against known elevations at river gages, reservoir bubbler locations, and at surveyed flood elevation locations. The elevations are compared in subwatershed subsections and indicate compliance with the CCSMP's Chapter 6 criteria to be within 6" of known elevations. No modeling adjustments (such as modification of Manning's n values) were required in order to meet elevation criteria.

The Lake Michigan Ravines watersheds are not monitored by river gages or other recording equipment or methods. As a result, the hydrologic modeling parameters of the HEC-HMS models were based on analysis of land use and topography. No modeling parameter adjustments were made to modify results to match recorded flow or elevation data.

Hydraulic modeling of Lake Michigan Ravine 1 was not calibrated due to lack of recorded flooding information. It is assumed that calibration and validation of the North Shore Channel modeling (downstream of the North Branch Dam) was performed by the USACE.

1.3.9 Flood Inundation Mapping

Flood inundation maps were produced to display the inundation areas associated with the 100-year event. The flood inundation maps were produced by overlaying the results of the hydraulic modeling on the ground elevation model of the watershed, which was derived from Cook County LiDAR data. In some areas, adjustments were made to the limits of inundation based on aerial photography and Cook County 2-foot contour data provided by the District.

1.3.10 Discrepancies between Inundation Mapping and Regulatory Flood Maps

Discrepancies may exist between inundation mapping produced under this DWP and regulatory flood maps. Discrepancies may be the result of updated rainfall data, more detailed topographic information, updated land use data, and differences in modeling methodology. A discussion of discrepancies is included in Appendix A.

1.3.11 Model Review

The hydrologic and hydraulic models developed under this DWP were independently reviewed by Christopher B. Burke Engineering, Ltd (CBBEL). CBBEL's review of the hydrologic models included a general verification of drainage areas, sub-basin divides, and hydrologic model parameters such as Curve Number and Time of Concentration. CBBEL's review of the hydraulic models included a general verification of roughness values, bank stations, ineffective flow areas, hydraulic structures, boundary conditions and connectivity with the hydrologic model output files. Recommendations from the independent review have been addressed in the hydrologic and hydraulic models developed to support the DWP.

1.4 Development and Evaluation of Alternatives

1.4.1 Problem Area Identification

Problem area data was generated from two sources. The first was community, agency and stakeholder response data that identified flooding, erosion, water quality, and maintenance problems recognized by the communities. In addition, problem areas were identified by overlaying the results of H&H modeling on the ground elevation model of the watershed to identify structures at risk of flooding along regional waterways. Modeled flood problems generally corroborated the communities' reported problems; however, in many instances, the model results also showed additional areas at risk of flooding for larger magnitude events. A secondary source of problem area identification was the existing FEMA FIRM panel maps. Areas shown within FEMA floodplain were carefully considered in H&H modeling and communication with communities in order to identify problem areas.

1.4.2 Economic Analysis

1.4.2.1 Flood Damages

Property damages due to flooding were assessed based upon the intersection of inundation areas for modeled recurrence intervals (2-, 5-, 10-, 25-, 50-, and 100-year) with the Cook County parcel data, considering ground elevation data, to calculate estimated flood depths. Damages were estimated using a methodology consistent with one developed by the USACE that estimates structure and contents damage as a fraction of structure value and based upon the estimated depth of flooding (USACE 2003). The general procedure estimating property damage due to flooding is outlined in Appendix F of the CCSMP. This method of damage calculation requires estimating a number of parameters for properties at risk of flooding which are detailed below.

Property damage values due to flooding are derived from the 2006 Cook County Tax Assessor (CCTA) data multiplied by a standard factor derived from a statistical analysis comparing recent sales data to the CCTA property values. The CCTA data includes tax assessed value of land, improvements, total tax assessed value, structure class (residential single family, multi-family, industrial etc.), number of stories, basement information, land area (square footage), and other data fields not relevant to this study.

1.4.2.2 Identification of Parcels at Risk of Flooding

Parcel boundaries were converted to points within the GIS application, and then the points were moved to the low side of structures at risk of flooding. Intersection of floodplain boundaries with parcel data was then performed for each modeled recurrence interval storm and used to identify parcels within the subwatershed that may, based upon their zero-damage elevations, be subject to property damage due to flooding for a particular recurrence interval.

1.4.2.3 Parcel Zero Damage Elevation

Structures do not incur damage due to flooding until the water surface exceeds the *zero-damage elevation,* at which water is assumed to begin flowing into the structure and cause damages. For most structures, the zero-damage elevation is the ground surface. Floodwaters exceeding the ground surface may enter the structure through doorways, window wells, and other openings within the structure. The zero-damage elevation was assumed to be the ground elevation for all parcels within the NBCR Watershed. The ground elevation estimate was obtained at the point representing the parcel, generally on the lower, stream-side of the actual structure.

1.4.2.4 Parcel First Floor Elevation

USACE depth-damage curves relate flooding depths to the first floor elevation of the structure, a value not provided within the CCTA data. First floor elevations (FFE) generally were not surveyed as it would require several thousand measurements. In general, a sample of several hundred field measurements of the FFE offset from ground elevation were collected to document expected values and variability of this component of the damage analysis. Based upon review of the collected first floor elevations, it was not possible to identify a pattern to predict the first floor elevation based upon factors such as subwatershed, estimated age of structure, or structure type. Furthermore, it was noted from pictures viewed on the CCTA website, that the average first floor elevation offset was roughly 18 inches, or slightly lower for structures that did not have basements. Based upon the data collected, first floor elevation offsets from ground elevation were estimated throughout the watershed as 18 inches for structures with basements, and 12 inches for structures without.

The only exception to the derivation of FFE presented above was the use of IDNR field survey of FFE for structures along the Middle Fork and Skokie River to calculate damages in areas that were shown as inundated through DWP modeling. It is noted that the IDNR FFE were used only where IDNR survey data was available; the previously described procedure of using 12 or 18 inch offsets from ground elevation was used to determine the remaining FFE for the Middle Fork and Skokie River reaches.

1.4.2.5 Structure Estimated Value

The estimated value of flooded structures is an input to damage calculations. The CCTA data included data that identified values for the land value as well as the improvement value (i.e., building, garage, etc.). The values in the CCTA data are assessed valuations of the estimated property value, which require a factor to bring the value, depending on the structure's use, to the CCTA estimation of property value. For example, residential structures receive an assessed valuation factor of 16 percent, thus the value identified by CCTA is the CCTA estimated value divided by a standardized 0.16. The adjusted CCTA data (reported values divided by the assessed valuation factor) was then compared with recent sales data throughout the county to statistically derive a multiplier that brings the 2006 CCTA estimated value of the properties to 2008 market value of properties. This multiplier was calculated to be 1.66. Since this plan analyzes damage to the structure, the land component of the property value was removed from the analysis. The value of the structure was computed by applying the assessed valuation multiplier and the District calculated market value multiplier to the improvement value identified in the CCTA data. This method was used on all property types to generate information to be used in the damage calculations.

1.4.2.6 Depth-Damage Curves

Six residential depth-damage curves were obtained from the USACE technical guidance memorandum EGM 04-01 (USACE, 2003) to relate estimated structure and contents damage to structure replacement value as a function of flooding depth. These damage curves are one story, two-story, and split-level resident structures, either with or without basements. For nonresidential structures, a depth-damage curve representing the average of structure and contents depth damage curves for a variety of structure types, generated by the Galveston District of the USACE was selected for use. Appendix F contains the depth-damage curves used to calculate property damage due to flooding. CCTA data was analyzed to identify the number of stories on residential structures and the presence or absence of a basement.

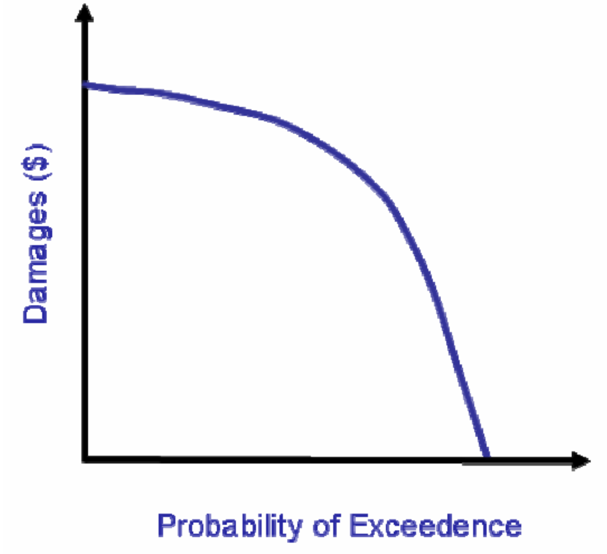
1.4.2.7 Property Damage Calculation

The estimated structure value, flooding depth, and depth-damage curve information were used to estimate the property damage from flooding for a specific structure due to a storm of given recurrence interval. Higher magnitude events, such as the 100-year event, cause higher damages for flooded properties but also have a lower likelihood of occurring in a given year. Figure 1.4.1 shows the hypothetical relationship between expected damage and modeled recurrence interval. Estimated annual damages were calculated according to Appendix F of Chapter 6 of the CCSMP, essentially weighting the expected annual damages by their annual probability of occurrence. Damages were then capitalized over a 50-year period of analysis, consistent with the period of analysis over which maintenance and replacement costs were calculated, using the federal discount rate for 2008 of 4.875 percent.

1.4.2.8 Erosion Damages

Locations of streambank erosion were identified through community response data. The CCSMP contains direction that erosion damages be estimated as the full value of structures at "imminent risk" of damage due to stream bank erosion, and that erosion damages not be assessed for loss of land. Field visits to areas identified as erosion problems were performed. Properties and infrastructure were judged to be at imminent risk if they were located within 30 feet of a site of *active erosion*, characterized by exposed earth, lack of vegetation, or collapsing banks. The estimated market value of the structure derived from CCTA data was used to estimate erosion damages for structures deemed at imminent risk. For infrastructure at risk other than property, such as roads and utilities, an estimate of the replacement value of these structures was used to assess erosion damages.

FIGURE 1.4.1
Hypothetical Damage-Frequency Relationship



1.4.2.9 Transportation Damages

Transportation damage generally was estimated as 15 percent of property damage due to flooding. In some specific instances, significant transportation damages may occur in absence of attendant property damage due to flooding. For the NBCR watershed, specific transportation damages were calculated when flooding fully blocked all access to a specific area in the watershed and these damages were not adequately captured as a fraction of property damages. In such instances, transportation damages were calculated according to FEMA guidance in the document "What Is a Benefit?" (FEMA, 2001). The duration of road closure was estimated for the modeled storms, and transportation damage was calculated according to a value of $39.82 (based on FEMA recommended rate of $32.23 in 2000 and brought forward to 2008 dollars using a 3.068% discount rate) per hour of delay per vehicle based on average traffic counts and the estimated time to detour around each flooded location.

1.4.3 Alternative Development and Evaluation

Potential stormwater improvements, referred to within the DWP as alternatives, were developed using a systematic procedure to screen, develop, and evaluate technologies consistently. Tributary-specific technologies were screened and evaluated in consideration of the stormwater problems identified through community response data and modeling. An alternative is a combination of the technologies developed to address the identified stormwater problems. In many instances, communities had suggestions regarding potential resolution of their stormwater problems, and their input was solicited during workshops and subsequent comment periods and was considered during alternative development.

Alternatives were evaluated with respect to their ability to reduce flooding, erosion, and other damages under existing conditions. The reduction in expected damages for an alternative is called a *benefit*. Conceptual level costs were developed for each alternative using countywide unit cost data that considered expected expenses such as excavation, land-acquisition, pipe costs, channel lining, etc. Standard countywide markups were used to account for the cost of utility relocation, profit, design engineering and construction management costs, and contingency. Expected maintenance and replacement costs were considered over a 50-year design period. Detailed design studies are required to confirm details associated with the feasibility of construction and precise configuration of proposed facilities.

Additional non-economic factors, such as the number of structures protected, the expected water-quality benefit, and the impact on wetland or riparian areas were considered in alternative development and evaluation.

1.4.3.1 Streambank Stabilization

Erosion control alternatives were developed to address problem areas where erosion problems on regional waterways were determined to threaten structures. Damages were calculated based on the value of the threatened structures. Erosion control alternatives considered a full range of alternative technologies as summarized in Table 1.4.2.

1.4.3.2 Flood Control

Flood control technologies were considered during the development of alternatives for addressing flooding problems, as summarized in Table 1.4.1. Conceptual alternatives were developed after selection of an appropriate technology or technologies for a problem area, and review of information provided by communities and/or obtained from other sources (such as aerial photography and parcel data) regarding potentially available land.

Hydrologic or hydraulic models for alternative conditions were created to analyze the effect of the conceptual alternatives. Initial model runs were performed to determine whether an alternative significantly affected water surface elevation (WSEL) near the target problem area, or had negative impacts in other parts of the tributary area. For models that resulted in significant reduction in WSEL, a full set of alternative conditions model runs was performed, and expected damages due to flooding were evaluated for the alternative conditions. Benefits were calculated based on damages reduced from existing to proposed conditions.

1.4.3.3 Floodproofing and Acquisition

Alternatives consisting of structural flood control measures may not feasibly provide a 100-year level of protection for all structures. The DWP identifies areas that will experience flooding at the 100-year event, even if recommended alternatives are implemented. Floodproofing and/or acquisition of such structures are nonstructural flood control measures that may reduce or eliminate damages during flood events, which is why these measures are listed in Table 1.4.1. However, due to the localized nature of implementing such solutions, the District may look to address structures that are candidates for nonstructural flood control measures under separate initiatives, outside of the Capital Improvement Program (CIP).

1.4.3.4 Water Quality

The potential effect of alternatives on water quality was considered qualitatively. Most detention basins built for flood control purposes have an ancillary water quality benefit because pollutants in sediment will settle out while water is detained. Sediments can be removed as a part of maintenance of the detention basin, preventing the pollutants from entering the waterway. Detention basins typically have a sediment forebay specifically designed for this purpose. Some detention basins could be designed as created wetland basins with wetland plants included which could naturally remove pollutants and excess nutrients from the basin. Streambank stabilization alternatives can help address water quality problems through reduction of sedimentation.

TABLE 1.4.1
Flood Control Technologies

Flood Control Option	Description	Technology Requirements
Detention/Retention		
Detention facilities (Dry basins)	Impoundments to temporarily store stormwater in normally dry basins.	Open space, available land. Only an upstream option.
Retention facilities (Wet basins)	Impoundments that include a permanent pool which stores stormwater and removes it through infiltration and evaporation. Retention facilities generally have an outfall to the receiving waterway that is located at an elevation above the permanent pool.	Open space, available land. Only an upstream option.
Pumped detention	Similar to detention or retention facilities, but includes a portion of the impoundment which cannot be drained by gravity and must be pumped out.	Open space, available land. Only an upstream option. Best applied when significant area is available to allow for filling only during large storms.
Underground detention	A specialized form of storage where stormwater is detained in underground facilities such as vaults or tunnels. Underground detention may also be pumped.	Space without structures, available land. Only an upstream option. Significantly more expensive than above ground facilities. Surface disruption must be acceptable during construction.

TABLE 1.4.1
Flood Control Technologies

Flood Control Option	Description	Technology Requirements
Bioretention	Decentralized microbasins distributed throughout a site or watershed to control runoff close to where it is generated. Runoff is detained in the bioretention facilities and infiltrated into the soil and removed through evapotranspiration.	Open space, multiple available opportunities for various sizes of open space.
Conveyance Improvement		
Culvert/bridge replacement	Enhancement of the hydraulic capacity of culverts or bridges through size increase, roughness reduction, and removal of obstacles (for example, piers).	Applicable only if restricted flow and no negative impact upstream or downstream. May require compensatory storage to prevent negative downstream impact. Permitting requirements and available adjacent land.
Channel improvement	Enhancement of the hydraulic capacity of the channels by enlarging cross sections (for example, floodplain enhancement), reducing roughness (for example, lining), or channel realignment.	No negative upstream or downstream impact of increased conveyance capacity. Permitting requirements and available adjacent land. Permanent and/or construction easements.
Flood Barriers		
Levees	Earth embankments built along rivers and streams to keep flood waters within a channel.	Permitting requirements and available adjacent land. Wide floodplains will be analyzed. Requires 3 feet of freeboard to remove structures behind levees from regulatory floodplain. Often requires compensatory storage.
Floodwalls	Vertical walls typically made of concrete or other hard materials built along rivers and streams to keep flood waters within a channel.	Permitting requirements and available adjacent land. Permanent and/or construction easements.
Acquisition	Acquisition and demolition of properties in the floodplain to permanently eliminate flood damages. In some cases, acquired property can be used for installation of flood control facilities.	Severe flooding, repetitive losses, other alternatives are not feasible.
Floodproofing		
Elevation	Modification of a structure’s foundation to elevate the building above a given flood level. Typically applied to houses.	Severe flooding, repetitive losses, other alternatives are not feasible
Dry Floodproofing	Installation of impermeable barriers and flood gates along the perimeter of a building to keep flood waters out. Typically deployed around commercial and industrial buildings that cannot be elevated or relocated.	Better suited for basement or shallow flooding. Need the ability to provide closure of openings in walls or levees. Plan for emergency access to permit evacuation.
Wet Floodproofing	Implementation of measures that do not prevent water from entering a building but minimize damages; for example, utility relocation and installation of resistant materials.	Most applicable for larger buildings where content damage due to flooding can be minimized. Waterproofing sealant applied to walls and floors, a floor drain and sump pump.

TABLE 1.4.2
Erosion Control Technologies

Erosion Control Option	Description	Technology Requirements
Natural (vegetated or bioengineered) stabilization	The stabilization and protection of eroding overland flow areas or stream banks with selected vegetation using bioengineering techniques. The practice applies to natural or excavated channels where the stream banks are susceptible to erosion from the action of water, ice, or debris and the problem can be solved using vegetation. Vegetative stabilization is generally applicable where bankfull flow velocity does not exceed 5 ft/sec and soils are more erosion resistant, such as clayey soils. Combinations of the stabilization methods listed below and others may be used.	Requires stream bank slopes flat enough to prevent slope failure based upon underlying soils. Channels with steep banks with no room for expansion or high bank full velocities (> 5 ft/sec) should avoid these technologies.
Vegetating by sodding, seeding, or planting	Establishing permanent vegetative cover to stabilize disturbed or exposed areas. Required in open areas to prevent erosion and provide runoff control. This stabilization method often includes the use of geotextile materials to provide stability until the vegetation is established and able to resist scour and shear forces.	
Vegetated armoring (joint planting)	The insertion of live stakes, trees, shrubs, and other vegetation in the openings or joints between rocks in riprap or articulated block mat (ABM). The object is to reinforce riprap or ABM by establishing roots into the soil. Drainage may also be improved through extracting soil moisture.	
Vegetated cellular grid (erosion blanket)	Lattice-like network of structural material installed with planted vegetation to facilitate the establishment of the vegetation, but not strong enough to armor the slope. Typically involves the use of coconut or plastic mesh fiber (erosion blanket) that may disintegrate over time after the vegetation is established.	
Reinforced grass systems	Similar to the vegetated cellular grid, but the structural coverage is designed to be permanent. The technology can include the use of mats, meshes, interlocking concrete blocks, or the use of geocells containing fill material.	
Live cribwall	Installation of a regular framework of logs, timbers, rock, and woody cuttings to protect an eroding channel bank with structural components consisting of live wood.	
Structural stabilization	Stabilization of eroding stream banks or other areas by use of designed structural measures, such as those described below. Structural stabilization is generally applicable where flow velocities exceed 5 ft/sec or where vegetative stream bank protection is inappropriate.	Applicable to areas with steep stream bank slopes (> 3:1) and no room for channel expansion, or areas with high velocities (> 5 ft/sec) can benefit from this technology.
Interlocking concrete	Interlocking concrete may include A-Jacks®, ABM, or similar structural controls that form a grid or matrix to protect the channel from erosion. A-Jacks armor units may be assembled into a continuous, flexible matrix that provides channel toe protection against high velocity flow. The matrix of A-Jacks can be backfilled with topsoil and vegetated to increase system stability and to provide in-stream habitat. ABM can be used with or without joint planting with vegetation. ABM is available in several sizes and configurations from several manufacturers. The size and configuration of the ABM is determined by the shear forces and site conditions of the channel.	
Riprap	A section of rock placed in the channel or on the channel banks to prevent erosion. Riprap typically is underlain by a sand and geotextile base to provide a foundation for the rock, and to pre-	

TABLE 1.4.2
Erosion Control Technologies

Erosion Control Option	Description	Technology Requirements
	vent scour behind the rock.	
Gabions	Gabions are wire mesh baskets filled with river stone of specific size to meet the shear forces in a channel. Gabions are used more often in urban areas where space is not available for other stabilization techniques. Gabions can provide stability when designed and installed correctly, but failure more often is sudden rather than gradual.	
Grade Control	A constructed concrete channel designed to convey flow at a high velocity (greater than 5 ft/sec) where other stabilization methods cannot be used. May be suitable in situations where downstream areas can handle the increase in peak flows and there is limited space available for conveyance.	
Concrete channels	Prevent stream bank erosion from excessive discharge velocities where stormwater flows out of a pipe. Outlet stabilization may include any method discussed above.	