The GLMRIS Report

Appendix E - Hydrologic & Hydraulic Analyses

USACE
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E.1 CAWS DEFINITION

Traditionally, what has been generally understood as the Chicago Area Waterway System (CAWS) definition has been the main waterway that is confined to the state of Illinois. For the Great Lakes and Mississippi River Interbasin Study (GLMRIS), the CAWS definition has been expanded to also include the aquatic pathways along the Little Calumet and Grand Calumet Rivers. For the purposes of GLMRIS, the following listing provides channel definition and length for what constitutes the CAWS for GLMRIS. These routes include mileage for the most direct (shortest) point-to-point distances between the Lockport Lock and Dam and the five (5) Lake Michigan access points.

Chicago River/Chicago Sanitary and Ship Canal

Main Stem: Lockport to Chicago River Controlling Works (CRCW) (Lake Michigan) - 36.1 mi
North Branch: Wolf Point to Wilmette Pumping Station (WPS) (Lake Michigan) - 15.2 mi

Cal-Sag Channel/Calumet River

Cal-Sag Channel: Junction of CSSC/ Calumet-Saganashkee (Cal-Sag) Channel to O'Brien Lock - 22.9 mi
Calumet River: O'Brien Lock to Lake Michigan - 6.7 mi

Little Calumet River

Little Cal: Cal-Sag Channel to Hart Ditch - 16.4 mi
Little Cal: Hart Ditch to Deep River - 11.5 mi
Burns Ditch: Deep River to Lake Michigan - 8.3 mi

Grand Calumet River

West Grand Cal: Calumet River to Indiana Harbor Canal - 6.1 mi
Indiana Harbor Canal to Lake Michigan - 5.1 mi

Total Length: 128.3 mi

Additional lengths which may be of interest (not included in the above calculation):

Bubbly Creek: Racine Avenue Pumping Station to South Branch of the Chicago River - 1.6 mi

North Branch Canal: Additional channel length around Goose Island - 0.9 mi

Indiana Harbor Canal: Lake George Branch - 1.4 mi

E.2 GLMRIS STUDY AREA AND CAWS TRIBUTARIES

The GLMRIS area includes the CAWS and its tributaries. The contributing drainage area of the CAWS is contained within the boundaries of Cook, DuPage, Lake, and Will counties in Illinois and Lake, Porter, and La Porte counties in Indiana.

The CAWS consists of a portion of the North Branch of the Chicago River, Chicago River, South Branch of the Chicago River, Little Calumet River, Burns Ditch, Grand Calumet River, Calumet River, North Shore Channel (NSC), CSSC, and Cal-Sag Channel. Flows in the Illinois portion of the CAWS are mainly effluent from the wastewater treatment plants (aka water reclamation plants) during dry weather and include treatment plant effluent, storm sewer, and combined sewer overflow (CSO) during wet weather. The CAWS also receives inflows from the non-navigable reaches of the North Branch of the Chicago River and many tributaries of the Chicago and Calumet river systems. In addition, the CAWS also receives water directly diverted from Lake Michigan at lakefront controlling works. The CAWS is a regulated waterway; it is controlled by Lockport Powerhouse and Lockport Controlling Works to the southwest and regulated by the WPS, Chicago River Controlling Works (CRCW), and O'Brien Lock and Dam to the northeast, east, and southeast, respectively.

The two largest tributaries of the CAWS are the North Branch of the Chicago River upstream from the NSC confluence and Hart Ditch. Other significant smaller tributaries that outlet directly into the CAWS include Thorn Creek, Midlothian Creek, East and West Stony Creek, Tinley Creek, Mill Creek, Navajo Creek, and Natalie Creek. Combined sewer overflows in the City of Chicago and other suburban areas that are not captured by the Tunnel and Reservoir Plan (TARP) tunnel and reservoirs are also another major source of inflow into the CAWS system along with outflow from Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) and other municipal wastewater treatment plants. Table E.1 presents some of the available stream gage information for the CAWS.

E.2.1 Grand Calumet and Little Calumet Rivers

Both the Grand Calumet and Little Calumet Rivers have a summit that divides flows to both directions. West of the divide water flows toward the Cal-Sag Channel, and eventually joins the Illinois waterway/Mississippi River. East of the divide, water flows toward Lake Michigan.

E.2.2 Little Calumet River

The Little Calumet River lies between its confluence to the Calumet River in Illinois and Lake Michigan at Burns Harbor in Indiana. The Great Lakes/Mississippi River watershed divide runs through the Little Calumet River near the Hart Ditch confluence. That is, the Little Calumet River west of the confluence is in the Mississippi River basin due to the construction of Burns Ditch in 1926, making a connection to Lake Michigan, whereas the river east of the confluence is in the Great Lakes basin. In 1922 a man-made canal, the Cal-Sag channel, was constructed. Since then, it has connected the Little Calumet River a few miles west of its confluence to the Calumet River to the CSSC, which eventually connects to the Mississippi River.

This is a permanent connection. There are culverts on the Little Calumet River that would impede flow but could not serve as barriers for aquatic nuisance species (ANS) transfer.

TABLE E.1 CAWS Stream Gages[a]

Site Name	Drainage Area	Gage Datum	Dates of Operation From	To
Chicago River Lock and Dam	n/a	579.48 NGVD29	1997-08-15	current
Chicago River at Columbus Dr.		579.48 NGVD29	1998-10-1	current
Illinois River at O'Brien Lock and Dam (POOL)	n/a	579.48 NGVD29		current
Illinois River at O'Brien Lock and Dam	n/a	579.48 NGVD29		current
Illinois River at O'Brien Lock and Dam (MET Station)	n/a	579.48 NGVD29		current
Chicago Sanitary & Ship Canal near Lemont, Illinois	738 sq mi	551.76 NAVD88	2004-12-07	current
CSSC at Lockport Controlling Works	740 sq mi	579.48 NGVD29	2010-3-10	current
Illinois River at Lockport Lock and Dam (POOL)	n/a	IGLD		current
Illinois River at Lockport Lock and Dam	740 sq mi	IGLD		current
Illinois River at Lockport Lock and Dam (MET Station)	740 sq mi	IGLD		current
North Branch of Chicago River at Albany Avenue at Chicago, Illinois	113 sq mi	580.67 NGVD29	1947-10-01	current
Little Calumet River at South Holland, Illinois	208 sq mi.	575.00 NGVD29	1947-10-01	current
Little Calumet River at Munster, Indiana	90 sq mi.	580.72 NGVD29	1958-07-01	current
Little Calumet River at Burr St, Indiana		584.88 NGVD29		current
Grand Calumet River at Hohman Ave. at Hammond, Indiana		575.00 NGVD29	1991-10-01	current
Indiana Harbor Canal at East Chicago, Indiana		570.20 NGVD29	1991-10-05	current

[a] Does not include MWRDGC gages.

During floods, a portion of flood water from Hart Ditch flows toward the west across the state boundary to join the Cal-Sag Channel; the other portion of flood water flows toward the east, combining with local inflows and finally exiting to Lake Michigan through Burns Harbor in Indiana. The Little Calumet River flows through a flood prone watershed characterized by flat terrain and watershed urbanization. Many levees, federal and local, exist along the Little Calumet River in Illinois and Indiana. The U.S. Army Corps of Engineers (USACE) has nearly completed a levee system (200-year level of protection) along the Little Calumet River between Gary and Hammond/Munster in Indiana. The levee was designed to protect a 200-year flood event with freeboard.

E.2.3 Grand Calumet River

The Grand Calumet River lies between its confluence to the Calumet River in Illinois and Lake Michigan at Indiana Canal Harbor in Indiana. The Great Lakes/Mississippi River watershed divide runs through the West Branch of the Grand Calumet River somewhere between the Hammond wastewater treatment plant outfalls and its confluence to the Indiana Canal depending on the water level on Lake Michigan. That is, the Grand Calumet River west of the divide is in the Mississippi River basin, whereas the river east of the divide is in the Great Lakes basin. In 1922 a man-made canal, the Cal-Sag Channel, was constructed to connect the Calumet River watershed to the Mississippi River via rivers and canals in Illinois.

This is a permanent connection. There are culverts on the Grand Calumet River that would impede flow but could not serve as barriers for ANS transfer.

E.3 CAWS HYDROLOGY

The flow patterns of the Chicago River, particularly in downtown Chicago, have been substantially modified by man, and these modifications have an impact on the flooding potential of the river. The North Branch of the Chicago River flows from north to south, parallel to the Lake Michigan shoreline, with its headwaters in Lake County. In Lake and northern Cook counties, there are three branches of the River (West Fork, Middle Fork, and Skokie River), which all come together north of Chicago, leaving only one stream channel, the North Branch, to flow through northern and central Chicago. The North Branch and much smaller South Branch join at Wolf Point in central Chicago about 2 mi west of the Lake, and the original flow of the Chicago River was from there eastward to the lake. This flow pattern has been changed by man in the late 1800s and early 1900s.

Historically, the Chicago River was a very important factor in the development of the City of Chicago, as it was part of an easy portage route for canoers, between the Great Lakes and Mississippi River systems. The city developed around the mouth of the river. However, the poor drainage of the river (due to flat topography), open sewer discharges into the river, and the river's discharge to Lake Michigan (the source of early residents' drinking water), led to severe health problems for city residents. To correct this problem, the entire city was raised 10 ft in elevation (to improve sewer drainage to the river), a system of combined intercepting sewers discharging to the Chicago River was built, and the flow of the river was changed by construction of the CSSC, a new, large canal connecting the South Branch of the river to the Des Plaines River. This man-constructed system, in conjunction with sluice gates and a lock at the old mouth of the Chicago River near the Lake Michigan shore, closing off discharge to the lake and forcing flow westward down the South Branch, had the capacity to carry all of Chicago's drainage and sewage away from the lake and down to the Illinois River and Mississippi River system. This work began in 1887 and was completed in 1900. This is the flow pattern of the river system today, with sewage treatment plants (constructed in the 1930s) that treat all the normal combined sewage flow before discharge to the river. The sluice gates and lock at the mouth of the river is called the CRCW.

Problems have arisen in the past when moderate to severe rainstorms, with large volumes of water entering the combined sewer system through city street drains and similar avenues of entrance, have exceeded the capacity of the combined sewers and the sewage treatment plants. Then the sewage is discharged directly into the Chicago River in the form of CSOs. If this overflow discharge, along with the direct runoff, is only moderate, the flow may still all continue down the CSSC to the Illinois River. However, on occasions when this inflow volume is so great that Chicago River stages threaten to overflow the river banks, the sluice gates and lock on Lake Michigan at the original mouth of the river (or one of the other controlling works on the river system) are opened to permit backflow to the lake, preventing flooding of the city.

There is also a lock and dam downstream on the CSSC (at Lockport), which affects upstream stages and flow patterns of the entire river/canal system. When heavy rains are forecast, the operation of pit gates in Lockport powerhouse is managed to draw down downstream stages of the river system prior to the storm to maximize Chicago River flow capacity without flooding. This procedure is always at least partially successful, but sometimes is not enough to prevent backflows to the lake (and potential flooding problems in the City of Chicago). There are other features of the entire system that affect flow in the Chicago River. These are the NSC, constructed in 1910, which runs from the WPS at the lakefront southward to the North Branch of the Chicago River in northern Chicago (near Lawrence Avenue). The WPS regulates the flow to and from the lake at this discharge point. The Cal-Sag Channel in southern Cook County connects the CSSC to the Little Calumet River. The Thomas J. O'Brien Lock, located on the Calumet River about 1/2 mi upstream of the confluence with the Grand Calumet River, controls flow between the river system and the lake at this point.

And finally, the TARP, sometimes known as the Chicago Underflow Plan (CUP), has been authorized, designed, and partially constructed. This is a project consisting of two very large reservoirs and an underground system of massive (up to 33 ft in diameter) sewer tunnels to convey large inflows of combined sewage to the reservoirs (and to be stored within the massive tunnel pipes) until the MWRDGC's sewage treatment plants can catch up with the inflow and begin treating this stored sewage before final, controlled discharge to the Chicago River system. This plan has been shown to be successful; however, it is not possible to store all the overflow of the combined sewage from a severe rainstorm. The TARP/CUP project, therefore, will eliminate discharges of untreated sewage to the Chicago River for moderate rainfall events, but will not eliminate all such discharges from severe rainfall events.

E.4 CONTROLLING WORKS ON THE CAWS

Lockport Lock and Powerhouse, Lockport Controlling Works, CRCW, O'Brien Lock and Dam, and WPS serve as controlling points to maintain proper water levels in the CAWS to facilitate navigation and prevent flooding. Facilities at CRCW, O'Brien Lock and Dam, and WPS also control the flows entering the waterway system from Lake Michigan, whereas Lockport Lock and Powerhouse and Lockport Controlling Works control the flows leaving the system in the downstream end.

The locks at the Lockport Lock and Powerhouse and the O'Brien Lock and Dam are owned and operated by USACE. The lock at Chicago Harbor is owned by the MWRDGC, but operated by USACE. The MWRDGC owns and operates other facilities at the Lockport Lock and Powerhouse, Lockport Controlling Works, WPS, and sluices gates at CRCW. One exception is that USACE owns the sluice gates at the O'Brien Lock and Dam, and operates these sluice gates under the direction of MWRDGC per a 1966 agreement between these two agencies.

The MWRDGC waterway operation has a control center in downtown Chicago that monitors the operating conditions of these facilities and river stages on the CAWS. Under normal conditions, water levels in most parts of the system are like a flat pool. When the MWRDGC receives a rainstorm forecast from the consultant, it starts allowing more flows to pass downstream of the system. This is achieved by passing more flow through the turbines or opening a sluice gate in the Lockport Powerhouse. In response to the increase of flow at Lockport, canal water level is lowered – most at Lockport — and lessened away from Lockport. This operation is often referred to as *canal drawdown*. Canal drawdown serves two purposes: first, it evacuates water in the canal system, preparing for anticipated large runoff to come, and second, it creates a steeper hydraulic gradient in the canal system that allows flood water to move out of the system faster. With very large rainstorm events, sluice gates at Lockport Controlling Works, which is located about 2 mi upstream from the Lockport Lock and Powerhouse, will also be opened to divert additional floodwaters to the adjacent Des Plaines River.

During severe rainstorms characterized by heavy and intense precipitation, the conveyance and storage of the canal system may become inadequate to handle floodwaters. Under this condition, sluice gates at CRCW, O'Brien Lock and Dam, and WPS may need to be opened. Water will be reversed from the waterway to Lake Michigan by gravity. During most severe rainstorm events, locks at CRCW and O'Brien Lock and Dam may also need to be opened in addition to opening of the sluice gates. This reversal of flow is also called *backflow*.

E.4.1 Lockport Powerhouse and Lockport Controlling Works

Lockport Powerhouse was built in 1900. It consists of two units of turbines and generators, nine pit gates, and a lock. The old MWRDGC lock was later replaced by a federal lock. During normal operation, one turbine usually runs to pass dry weather flow downstream to maintain a relatively flat pool and adequate depth of water between a 36-mi stretch of the waterway between Lockport and the lakefront to support navigation. Pit gates are used to pass floodwaters downstream. Lockport Controlling Works is located about 2 mi upstream from the Lockport Powerhouse. It consists of seven sluice gates that can divert floodwaters from the CAWS to the Des Plaines River, in addition to the pit gates in the powerhouse, during significant flood events. Coordinated operation of the pit gates in the powerhouse and the sluice gates at the controlling works is one of the key elements in the operations of CAWS. The MWRDGC owns and operates all equipment and structures in the Lockport Powerhouse and Controlling Works except for the lock, which is operated by the Rock Island District of USACE.

E.4.2 Chicago River Controlling Works

The CSSC was the first man-made canal in the CAWS. It was completed in 1900; the canal connects the Chicago River to the Illinois River and remaps several hundred square miles of the Great Lakes Basin to the Upper Mississippi River Basin. The CRCW was built in 1938 to reduce lake diversion and provide better flood control to downtown Chicago. Figure E.1 shows the CRCW, which consists of a low-lift lock and two sets of sluice gates.

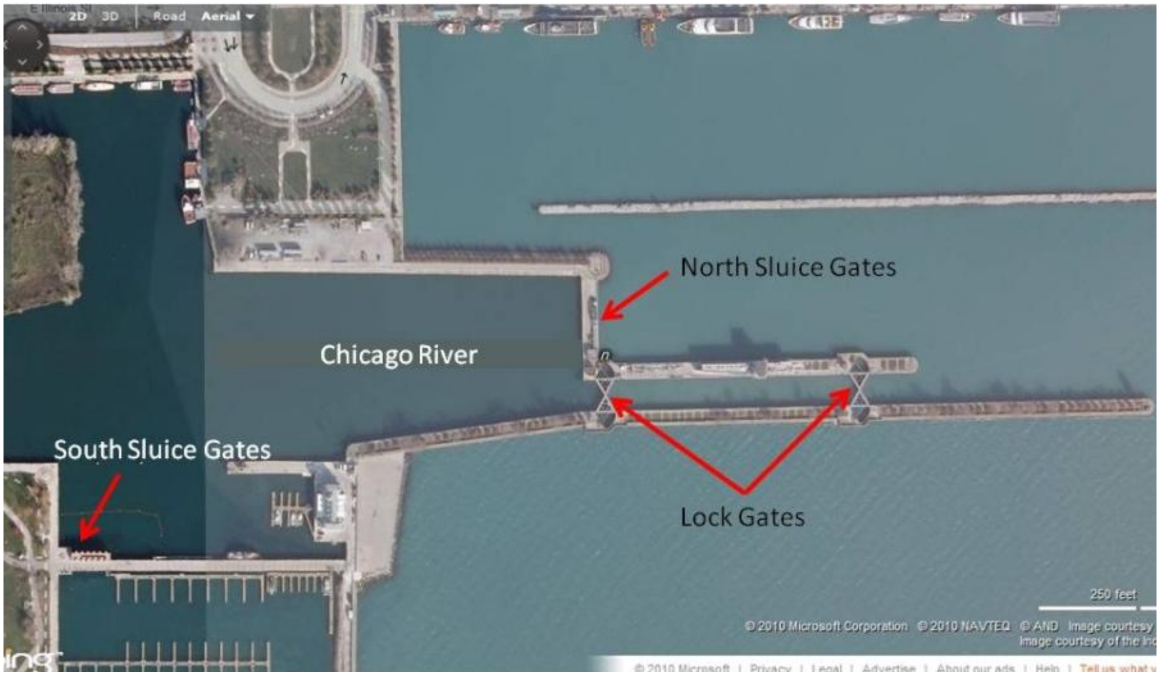

FIGURE E.1 Chicago River Controlling Works at the Mouth of Chicago River

Each set of sluice gates contain four 10-ft by 10-ft sluice gates. The south sluice gates were moved to the new turning basin cutoff wall in 2000. The new south sluice gates are routinely used for diverting lake water for maintaining mandated water elevation on the Chicago River at Chicago and reasonably sanitary conditions in the CAWS. The north sluice gates are routinely exercised once every other month to ensure they are in an operable condition. To reduce the risk of Asian carp entering Lake Michigan, bar screen has been installed to two sluice gates: one in the south gate group and the other in the north gate group. The gates without screen will not be used for diversion. During severe rainstorm events opening all sluice gates and possibly the lock as well to reverse floodwaters to Lake Michigan is often needed to prevent flooding in downtown and central Chicago. USACE operates the lock, whereas the MWRDGC owns the structures at the CRCW and operates the sluice gates. Table E.2 shows the historical records of backflow at the CRCW since 1949; most flow reversal events occur during the summer months. Eleven events have occurred since 1986, and six out of these eleven events involved lock gate opening.

TABLE E.2 Historical Records of Backflow at CRCW

Date	MG*	Date	MG*
10/9-10/10/54[L]	970	5/9-5/10/90	208
7/14/57[L]	2,260	11/27-11/28/90	86
9/14/61[L]	718	7/17-7/18/96	519
8/17/68[L]	533	2/20-2/22/97	1,947
8/26/72	59	8/16-8/17/97	402
4/18/75	1,130	8/2/01[L]	833
6/30/77	297	8/22/02[L]	1,296
7/21/80	184	9/13-9/14/08[L]	5,438
8/7/82	83	7/24/10[L]	5,703
12/2-12/3/82	248	7/23/11[L]	1,716
8/13-8/14/87[L]	986	4/18/2013[L]	6,105

*** MG = Million Gallons** **[L] Events Lock Gates Opened**

E.4.3 Wilmette Pumping Station

The NSC was completed in 1910 and connects the North Branch of the Chicago River to Lake Michigan. The NSC does not have a commercial navigation function, but it can divert lake water to improve water quality in the canal itself and the North Branch of the Chicago River between its confluence and downtown Chicago. Besides, the NSC can convey floodwaters from the upper portion of the waterway to Lake Michigan during severe rainstorm events. At the mouth of NSC, a pumping station, that is, the WPS, was constructed at the same time as the canal. Figure E.2 shows the picture of the WPS. The WPS is currently undergoing a major rehabilitation. The construction is expected to be completed in 2014. At that time, the WPS will include one 150-cfs variable speed pump, which will be the primary diversion pump, and the rebuilt 250-cfs pump, which will be used as a backup. In addition, three sluice gates will replace the existing 32-ft x 15-ft gate for backflow operation (MWRDGC 2010).

FIGURE E.2 Wilmette Controlling Works at the Mouth of North Shore Channel

Because of the concern of Asian carp, the sluice gate at this site is no longer used for diversion, although gravity flow through the gate is more economical than pumping flow. MWRDGC owns and operates the WPS.

Table E.3 shows the historical records of backflow at the WPS since 1986; backflow at the WPS is more frequent than that at the other two lakefront controlling works.

TABLE E.3 Historical Records of Backflow at the WPS

Date	MG*	Date	MG*
10/3/86	53	10/13/01	91
8/13-8/14/87	971	8/22/02	455
8/25-8/26/87	18	8/23-8/24/07	224
8/3-8/4/89	52	9/13-9/14/08	2,942
5/9-5/10/90	289	12/27-12/28/08	461
8/17-8/18/90	10	2/26-2/27/09	79
11/27-11/28/90	154	3/8/09	143
2/20-2/22/97	774	6/19-6/20/09	192
8/16-8/17/97	157	7/24/10	750
6/13/99	10	5/29/11	107
8/2/2001	140	7/23/11	504
8/31/2001	75	4/18/13	1,429

*** MG = Million Gallons**

E.4.4 O'Brien Lock and Dam

The Cal-Sag Channel, which was completed in 1922, connects the Calumet watershed to the CSSC. This man-made waterway also converts a sizable amount of Great Lakes Basin to the Upper Mississippi River Basin. The Cal-Sag Channel was enlarged in 1960. In 1965 the O'Brien Lock and Dam was built on the Calumet River to replace the Blue Island Lock on the Little Calumet River. The O'Brien Lock and Dam consists of a low-lift lock and four sluice gates. To reduce the risk of Asian carp entering Lake Michigan a metal screen has been installed on one sluice gate for diversion. During severe rainstorm events, opening all sluice gates and possibly the lock as well to reverse floodwaters to Lake Michigan is often needed to prevent flooding in southern Chicago areas. Figure E.3 shows the O'Brien Lock and Dam. The USACE owns and operates the facilities at this location.

Table E.4 shows the historical records of backflow at O'Brien Lock and Dam since 1965; most flow reversal events occur during the summer months. Four events have occurred since 1986, and half of these events involved lock opening.

FIGURE E.3 O'Brien Lock and Dam on the Calumet River

TABLE E.4 Historical Records of Backflow at O'Brien Lock and Dam

Date	MG*	Date	MG*
12/24-12/25/65[L]	898		
5/12/66[L]	1,152		
6/13/81	377		
12/2-12/3/82	124		
11/27-11/28/90	224		
7/17-7/18/96	1,032		
2/20-2/22/97[L]	1,458		
9/13-9/14/08[L]	2,669		
4/18/2013	3,017		

*** MG = Million Gallons** [L] **Events Lock Gates Opened**

E.5 HYDROLOGIC AND HYDRAULIC MODELS

Many different hydrologic and hydraulic computer models were used to model the complex hydrology and hydraulics of the CAWS for GLMRIS. Table E.5 below presents a listing of the hydrologic and hydraulic models used for GLMRIS.

Figure E.4 shows the data flow and how the hydrologic/hydraulic and economic models are linked for modeling the overbank flooding.

TABLE E.5 Hydrologic and Hydraulic Models Used for GLMRIS

River	Hydrologic Model		Hydraulic Model	
Chicago Area Waterway System (CAWS)	HSPF/SCALP	USACE	Unsteady HEC-RAS	USACE (AECOM)
			DUFLOW	MWRDGC/USACE (Dr. Melching)
Upper North Branch of Chicago River	HEC-HMS	MWRD (HDR)	Unsteady HEC-RAS	MWRD (HDR)
	HEC-1 (Lake County, Ill.)	USACE		
Little Calumet River	HEC-HMS	MWRD (CDM et al.)	Unsteady HEC-RAS	MWRD (CDM et al)
	HEC-1	USACE	Unsteady HEC-RAS	USACE
Grand Calumet River (coupled with CAWS)	HSPF/SCALP	USACE	Unsteady HEC-RAS	USACE
	HSPF/SCALP	USACE	UNET	USACE
Cal-Sag Region	HEC-HMS	MWRD (CH2M Hill)	Unsteady HEC-RAS	MWRD (CH2M Hill)
Sewer Network (City of Chicago)	InfoWorks	The City of Chicago (CDM et al.)	InfoWorks	The City of Chicago (CDM et al)
Sewer Network (Suburban Communities)	InfoWorks	USACE (CH2M Hill)	InfoWorks	USACE (CH2M Hill)

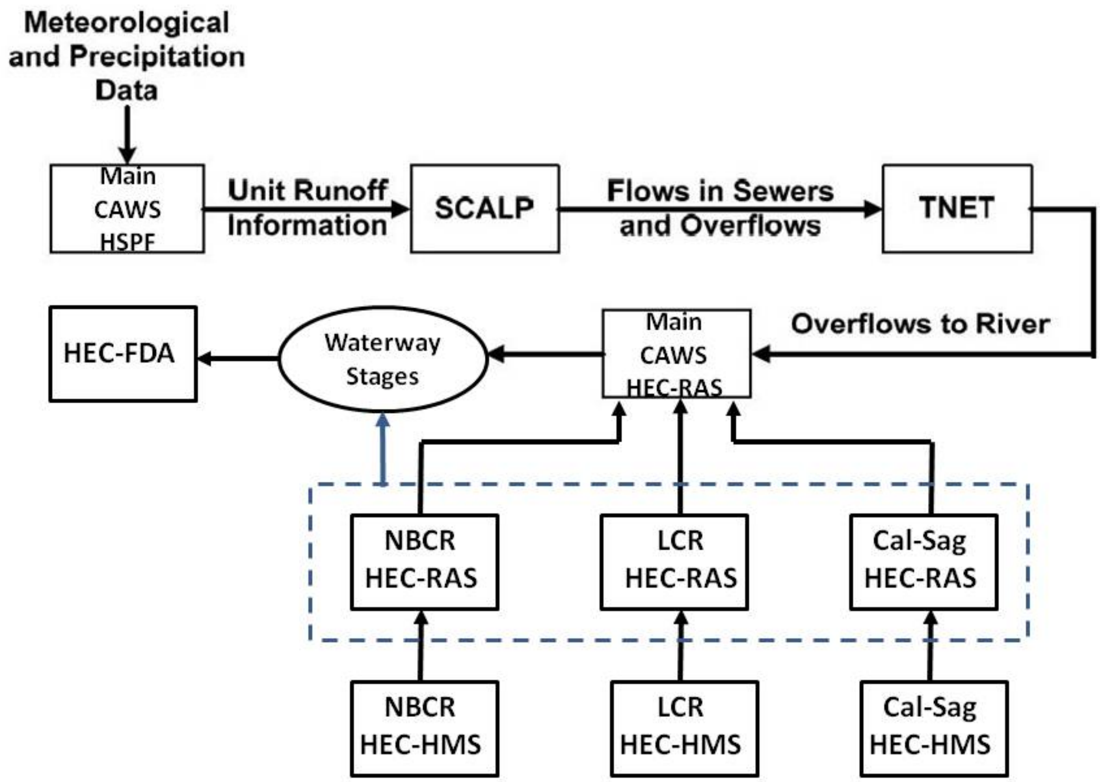

FIGURE E.4 Data Flow Diagram between Hydrologic and Hydraulic and Economic Models for Overbank Flood Modeling

The backwater effect on the North Branch of the Chicago River and Little Calumet River diminishes a few miles upstream from their confluence with the main CAWS. Proper downstream boundary conditions were considered while the MWRDGC was developing these models as part of its studies of a Detailed Watershed Plan (DWP). In most cases, the simulated or estimated flood stage hydrographs on the CAWS were used as the downstream boundary condition. With GLMRIS, it is an iterative procedure. Tributary models were first run to produce inflows to the CAWS, and they were rerun using the stages by the CAWS model as the new downstream boundary condition. On the other hand Grand Calumet River has a mild slope throughout its entire length between its confluence at the CAWS and Indiana Harbor Canal. In this case, the Grand Calumet River model was coupled with the CAWS to provide seamless results. Note that the stages computed from the decoupled and coupled Grand Calumet River models do not show much difference. This provided a certain level of confidence that the conventional decoupled modeling approach is still practical for the current study.

As stated in the main report, GLMRIS will not provide a solution to prevent ANS transfer between the Great Lakes and Mississippi River basins; rather, the project will prevent or reduce the risk of ANS interbasin transfer to the maximum extent possible. The proper level of protection depends mainly on the consequences of failure in protection. If the consequences involve human life casualty, public health or significant loss of property, the protection level will be high and a hydrologic event at the Standard Project Flood (SPF) or even Probable Maximum Flood (PMF) level may be considered. With GLMRIS, the consequences pertain to the potential socioeconomic and environmental impact on the ecosystem to be protected. With these considerations in mind, a 500-year (or 0.2% chance of exceedance) level of protection was adopted for the project. Besides the probability of the rain event that can create a pathway over or around the designed physical barriers, the probabilities of survival, colonization, and spread for the ANS also influence the overall risk of ANS transfer.

E.5.1 Hydrologic Models

Hydrologic models are used to transform rainfall to runoff and to route runoff to the water reclamation plants, TARP, or CAWS as overflows during rainstorm events. With the risk-based design in mind for GLMRIS, eight events (1, 2, 5, 10, 25, 50, 100, and 500 years) were chosen. The depth and distribution of precipitation follow the guidelines documented in *Illinois State Water Survey* (*ISWS) Bulletins 70* and *71*. Precipitation durations of 3, 12, 24, and 48 hr were analyzed, and a critical duration was determined by examining the preliminary modeling results. This critical duration was used in the final production run. An areal reduction factor was used to reduce the point precipitation depth to the uniform areal precipitation throughout the watershed tributary to the CAWS.

An important and often overlooked issue is the appreciable error associated with precipitation frequency estimates. In *National Oceanic and Atmospheric Administration* (*NOAA*) *Atlas 14* the upper and lower bounds of the 90% confidence interval around the estimates were published; these can range from approximately ±10% to ±30%. Traditional engineering practice has not accounted for this type of error before because quantification of the error was not available. The new error estimates in *NOAA Atlas 14* may (or may not be) in the same order of magnitude as the potential impact of climate change. Table E.6 shows the depth of precipitation for the 500-year rain event based on *ISWS Bulletin 70* (extrapolated from the probabilistic curves) versus *NOAA Atlas 14*.

TABLE E.6 Design Precipitation Depths

	ISWS Bulletin 70	*NOAA Atlas 14* (90% Confidence Interval)	Difference (%)
NBCR Basin	10.9	9.35 (7.74-10.8)	16.6%
Little Calumet River Basin	11.0	9.79 (8.37-10.8)	12.4%
Cal-Sag Basin	10.43	10.1 (8.43-11.3)	3.3%
Central Basin	9.30	9.72 (8.43 – 11.3)	-4.7%

Given that the point estimate can be ±10% to ±30% off the true value, the rainfall depths from the Depth-Duration-Frequency (DDF) curves in *ISWS Bulletin 70* versus those in *NOAA Atlas 14* are comparable.

A large portion of the watershed is serviced by combined sewer systems. The sewer network, which consists of lateral, submain, and main trunk sewers and intercepting sewers, collects storm runoff and sanitary flows and conveys them to the water reclamation plants (sewage treatment plants or waste water treatment plants). When the combined sewer flows exceed the plant capacity, they will be diverted to TARP if the sewer has a drop shaft connection to the TARP system and the TARP system has available storage. Otherwise, excess flows will be directed to the CAWS via CSO discharge points, that is, outfalls, along the waterway. The prior occupancy of the TARP system at the onset of the design rain event can affect the water levels in the CAWS. It was assumed in the analyses that the CUP reservoirs would be empty at the beginning of the design rain event, and a sensitivity analysis was performed to show how significant this parameter would affect the water levels on the CAWS as well as the size of the flood mitigation reservoir required for the with-project condition.

E.5.1.1 HSPF

Hydrologic Simulation Program Fortran (HSPF) was used to simulate unit runoff (i.e., the depth of runoff per unit area) hydrograph in response to synthetic rainstorm events. Inputs to the model include hourly hydro-meteorological data (precipitation, air temperature, dew point temperature, wind speed, cloud cover, and solar radiation), land topographic, and soil physical properties. Three types of land cover are considered in HSPF modeling: impervious, grass, and forest. There are a couple dozen parameters related to soil moisture accounting for pervious lands. The U.S. Environmental Protection Agency (EPA) provided typical range of these parameters, and modelers adjusted these parameter values to calibrate the model. The HSPF model for the CAWS watershed has been continuously reviewed and improved by Lake Michigan diversion accounting. Since most of the combined sewer area in the Metropolitan Chicago area is ungaged, regional parameter transfer methodology was used in model calibration. In addition, the hydrologic model was calibrated and verified by water balance checks at MWRDGC's water reclamation plants and the entire waterway system.

E.5.1.2 SCALP

Special Contributing Area Loading Program (SCALP) was used to compute sewer inflow and infiltration from each special contributing area (SCA), that is, the subcatchment area, by multiplying the surface and subsurface unit runoff computed by HSPF by the land cover areas. SCALP was also used to compute the sanitary flow from SCA and to route the combined sewer or sanitary flow to the water reclamation plant. In the process it also computes the excess flow that goes to TARP or the waterway. Routing in SCALP is based on hydrologic inflow-outflow-storage modeling. The areas of impervious, grass, and forest lands for each SCA are input to SCALP along with a few routing parameters, which include the storage coefficient and split flow discharge. Output from SCALP includes the hydrographs for the flows routed to the water reclamation plant and overflows. The SCALP model has been used in conjunction with HSPF and TNET to model the hydrology in the ungaged CAWS watershed.

E.5.1.3 HEC-HMS

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems, including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.

HEC-HMS was used to model most of the rainfall-runoff hydrology for the tributaries of the CAWS. HEC-HMS models developed by the MWRDGC in relation to the DWP for the North Branch of the Chicago River basin, the Little Calumet River basin, and the Cal-Sag area watersheds were used to develop the tributary inflows for the CAWS HEC-RAS model.

E.5.1.4 HEC-1

HEC-1 is the legacy software to HEC-HMS and has similar basic functionality. All ordinary flood hydrograph computations associated with a single recorded or hypothetical storm can be accomplished with this software package. For the Lake County, Illinois, portion of the North Branch of the Chicago River, MWRDGC used the regulatory HEC-1 model for the rainfall-runoff hydrology model to develop inflows into the HEC-HMS model at the northern boundary of Cook County.

E.5.1.5 SWMM

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single-event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas on which rainfalls and runoff are generated. The routing portion of SWMM transports this runoff through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprising multiple time steps.

SWMM was used to develop the rainfall-runoff hydrology for input into the InfoWorks sewer modeling. The SWMM hydrology is independent of the CAWS model hydrology.

E.5.2 Hydraulic Models

Hydraulic modeling uses the inflows from the hydrologic modeling as the forcing function to drive water movement in conduits or open channels. The governing equations of one-dimensional unsteady water flow in the conduit or open channel include the continuity equation and the equation of motion, that is, Saint Venant equation. Stage and discharge are two unknown physical parameters to be solved at all model nodes for each time step. To model the CAWS, two hydraulic models were developed: TNET and HEC-RAS. The InfoWorks model was used as the hydraulic model for the sewer network modeling.

E.5.2.1 TNET

The Tunnel NETwork (TNET) program was used to model the hydraulics of sewer flows in TARP. TNET computes the discharge hydrographs of the TARP pumping stations that pump captured flood waters to the water reclamation plants when the plants have unused capacity to process sewer flows in addition to the flows coming to the plants through the intercepting sewers. The TNET model was developed by Dr. Robert Barkau in 1990s. The model is based on solving the one-dimensional unsteady continuity and Saint Venant equations by using an implicit finite difference numerical scheme. The major inputs to the TNET model are the overflows computed by SCALP, and the major outputs from the model include the discharge hydrographs for the flows pumped to the water reclamation plant and the hydrographs of excess flow discharged to the waterways near the drop shaft locations. The pumps at the Mainstream and Calumet TARP Pumping Stations during significant rainstorms are usually not in operation because Stickney and Calumet Water Reclamation Plants are overwhelmed by sewer flows from the intercepting sewers. The overflows computed by the TNET model are input to the HEC-RAS model as a major part of the unsteady flow boundary conditions.

E.5.2.2 HEC-RAS Unsteady Flow Model

The River Analysis System (RAS) computer model developed by the USACE Hydrologic Engineering Center (HEC) was used to model the hydraulics of the CAWS. The unsteady HEC-RAS model computes stages and discharges in the CAWS in response to inflows computed by TNET and the inflows from the tributary models that were developed by the MWRDGC in relation to the DWPs for the North Branch of the Chicago River, the Little Calumet River, and the Cal-Sag area watersheds. The controlling works in the CAWS were modeled by the inline and lateral structures as stage-controlled gates or the rule-based controlled gates.

Cross Section Data. The echo sounder hydrographic survey data were collected by the USACE Rock Island and Detroit Districts. The bathymetric survey covered the navigable portions of the CAWS. Recent survey data for the upper portion of the North Branch of the Chicago River, the NSC, and Grand Calumet River are not available. The cross sections included in the previous UNET models were reviewed and geo-referenced before being integrated into the HEC-RAS model.

Storage Areas. Additional storage areas were added to the CAWS model for GLMRIS to better model areas that would be flooded for extreme flood events. The storage areas were delineated by the geographic information system (GIS) software, and Lake Michigan is also modeled as one of the storage areas.

Control Structures. The water level and flow in the CAWS are regulated by five control structures: CRCW, O'Brien Lock and Dam, WPS, Lockport Powerhouse, and Lockport Controlling Works. During normal conditions, the water level in the CAWS is maintained with a very mild slope that allows dry weather flow, primarily consisting of the wastewater discharges from the water reclamation plants, to move downstream to the Illinois River through the turbine in the Lockport Powerhouse. Prior to and during a rainstorm event, additional flow would be passed through the turbine as well as one or two pit gates in the powerhouse to draw down the canal, preparing for large runoff and flood discharge.

Chicago River Controlling Works. In the HEC-RAS modeling for the CAWS, the east and west lock gates of the Chicago Lock are represented by two separate gate structures. The gate type is modeled as overflow gate open to air, because these lock gates swing open and close in a horizontal plane. The discharge through the lock gates is controlled by the broad-crest weir. A discharge coefficient of 3.0 is used. The south sluice gates are represented by four separate gates. The gate type is modeled as sluice gate. The discharge through the sluice gate is controlled by the sluice gate, submerged orifice, or weir flow, depending on the water levels on the river and lake. However, in most cases, the flow regime behaves as discharge through a submerged orifice. The four north sluice gates are modeled in the same manner as the gates in the cutoff wall to the south. The sluice gates are used for diverting lake water to the CAWS (i.e., navigation makeup) during the canal drawdown prior to the design rain event, and the same sluice gates are also used for reversing floodwater in the CAWS to Lake Michigan during significant rain events. The water levels in the CAWS that trigger the gate open or closed for these two operations are different. Therefore, for modeling convenience a couple of fictitious gates are included in the model to represent two physical gates that are being used for diverting navigation makeup water per the Code of Federal Regulations (CFR) navigation regulation. These two fictitious gates have the same dimensions and invert elevation as the real gates, and they are created for modeling convenience without compromising any model accuracy. In the HEC-RAS model, the water levels that trigger opening the gates are specified to mimic the real gates for backflow operation, whereas a different set of opening and closing levels are specified for the fictitious gates for diversion operation.

O'Brien Lock and Dam. Figure E.5 (USACE 1986)) shows the key elevations of the O'Brien Lock and sluice gates. The lock gate sill is at −18.5 CCD, and the top of the lock wall is at +7 CCE. The invert elevation of the gate sill for all four 10-ft by 10-ft sluice gates is at −13.0 CCE.

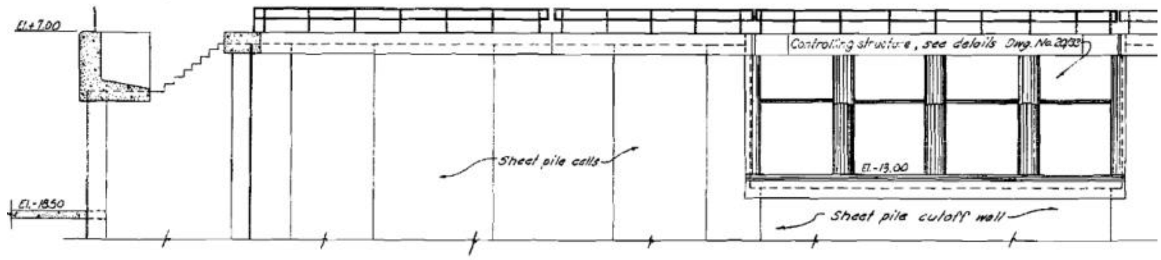

FIGURE E.5 Cross Section of O'Brien Lock and Sluice Gates

The south and north lock gates are represented by a single gate structure. The gate type is modeled as overflow gate open to air, because these lock gates open and close in a horizontal plane. The discharge through lock gates is controlled by the broad-crest weir. A discharge coefficient of 2.6 is used. The four sluice gates are represented by a single gate group. The gate type is modeled as sluice gate. The discharge through the sluice gate is controlled by the sluice gate, submerged orifice, or weir flow, depending on the water levels in the Calumet River and lake. However, in most cases, the flow behaves as discharge through a submerged orifice.

Wilmette Pumping Station. Figure E.6 (USACE 1986) shows the cross section of the WPS. The pump house is in the middle of Figure 6, and the sluice gate next to the pump house has a width of 32 ft and can be opened up to 15 ft. The sluice gate at the WPS is represented by a single gate in HEC-RAS. The gate type is modeled as sluice gate. The discharge through the sluice gate is controlled by the sluice gate, submerged orifice, or weir flow, depending on the water levels in the North Shore Channel and lake. However, in most cases, the flow behaves as discharge over a broad-crest weir.

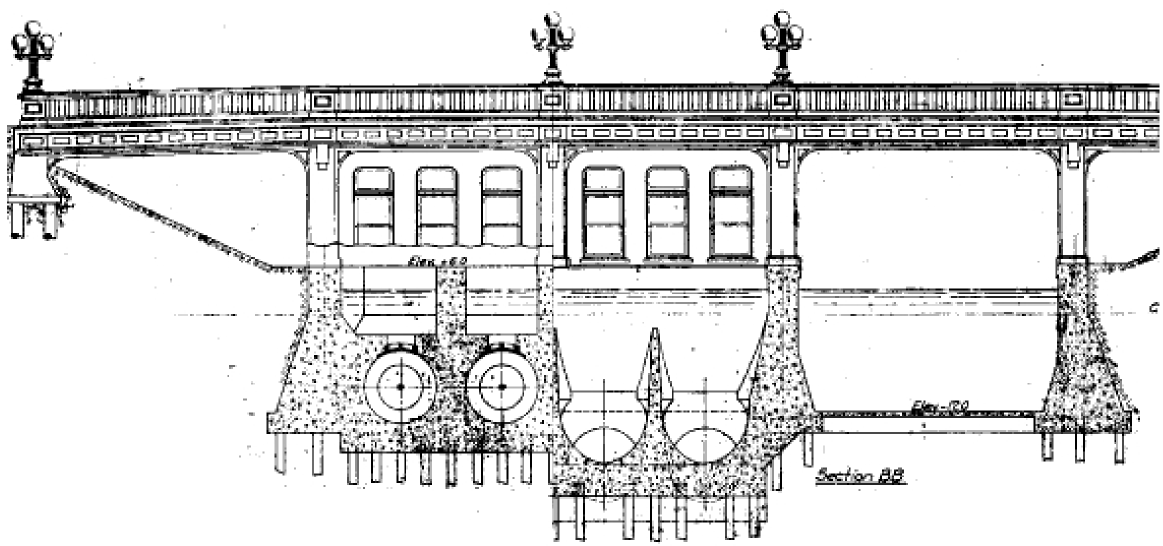

FIGURE E.6 Cross Section of Wilmette Pumping Station

Lockport Powerhouse. Lockport Powerhouse includes two turbines and nine (9) pit gates. The pit gates are grouped in three bays, each of which is 14 ft high by 9 ft wide and can be operated separately. Pit gates are opened to pass floodwaters downstream. Due to vibration concern, a pit gate will be either open or closed and will not be stopped at the partially open position.

Lockport Controlling Works. Lockport Controlling Works is located at about 2 mi upstream from Lockport Powerhouse. It consists of seven (7) sluice gates whose normal position is perpendicular to the main flow in the CSSC, and each is 20 ft high by 30 ft wide. They are modeled as a lateral gate structure in HEC-RAS.

CUP Reservoirs. The GLMRIS baseline year is 2017 as determined by the Economics Team. The hydrologic and hydraulic modeling for this baseline condition includes the stormwater storage effect of the TARP tunnels and also the storage capacity of McCook Stage I and Thornton reservoirs. The future condition model will also include McCook Stage 2. See Table E.7 for the current reservoir completion schedule as provided by MWRDGC.

TABLE E.7 TARP Reservoir Schedule

Year of Completion	Reservoir
2003	Thorn Creek transitional reservoirs (3.1 BG/9,600 acre-ft)
2015	Thornton (7.9 BG/24,200 acre-ft total)
2017	McCook Stage 1 (3.5 BG/10,800 acre-ft)
2029	McCook Stage 2 (10 BG/30,600 acre-ft final total)

Boundary Conditions. Boundary conditions include rule-controlled gates at the CRCW, O'Brien Lock and Dam, and WPS; rule-controlled gates at Lockport Powerhouse and Lockport Controlling Works; inflows from the North Branch of the Chicago River at Albany Avenue; Little Calumet River at its junction to the Cal-Sag Channel; and various small tributaries in the Cal-Sag Channel watershed. In addition, boundary conditions include inflows from the water reclamation plants and a number of CSO outfalls. Lake Michigan is modeled as a storage area of which a constant stage is specified.

Initial Condition. Base flows were specified to each reach of the CAWS model. The initial water levels in the waterways and storage areas were computed and water levels quickly converged to an "equilibrium" condition before storm runoff reaches the CAWS. Therefore, the simulated stage and discharge hydrographs during significant rainstorm events would not be sensitive to the initial condition.

Model Calibration. The unsteady HEC-RAS model was calibrated by using the rainstorm events in August 2001, August 2002, and September 2008. The sluice gates and lock at the CRCW and the WPS were opened during the first two events, whereas the sluice gates and lock at all three lakefront structures were opened during the September 2008 event. Details of model calibration are documented in references (AECOM 2010 and Schmidt 2012).

Controlling Works and Canal Operation Rules. The baseline condition reflects the current plans of hydraulic structures at controlling works and the waterway operation rules. The operation rules include the minimum water levels that need to be maintained at Lockport Controlling Works, Cal-Sag Channel Junction, Chicago Lock and O'Brien Lock during drawdown, and the open and closed elevations of water levels at the CRCW, O'Brien Lock and Dam, and the WPS. These rules are documented in MWRDGC's Waterway Operation Manual. These rules were programmed into the HEC-RAS model. The lock and sluice gates at the lakefront controlling works would be opened only when the river level is higher than the lake level.

E.6 FUTURE CONDITION

E.6.1 Land Use

Many of the drainage areas of the CAWS such as the upper CSSC, Chicago River, and Calumet River, are fully built out with little change in the land use over the last few decades. Areas where some change might be expected are in the two major tributaries of the CAWS such as in the North Branch of the Chicago River Basin or the Little Calumet River Basin. Tables E.8 and E.9 present land use data for these two river basins for the years 1992, 2001, and 2006. Figure E.7 shows the delineation of the North Branch of the Chicago River upstream from the gaging station at Niles, Illinois, and Figure E.8 shows the boundary of the Little Calumet River upstream from the U.S. Geological Survey (USGS) gaging station at South Holland, Illinois. The tables show small relative changes in land use between 1992 and 2001 based on the National Land Cover Data (NLCD) datasets, and leveling off of land use or basically no change from 2001 to 2006. This would indicate that overall land use of the CAWS watershed appears to be stabilizing with little relative change expected in the near future, based on extrapolation of the latest observed data. The land cover was calculated from land use based on the NRCS TR-55 procedures.

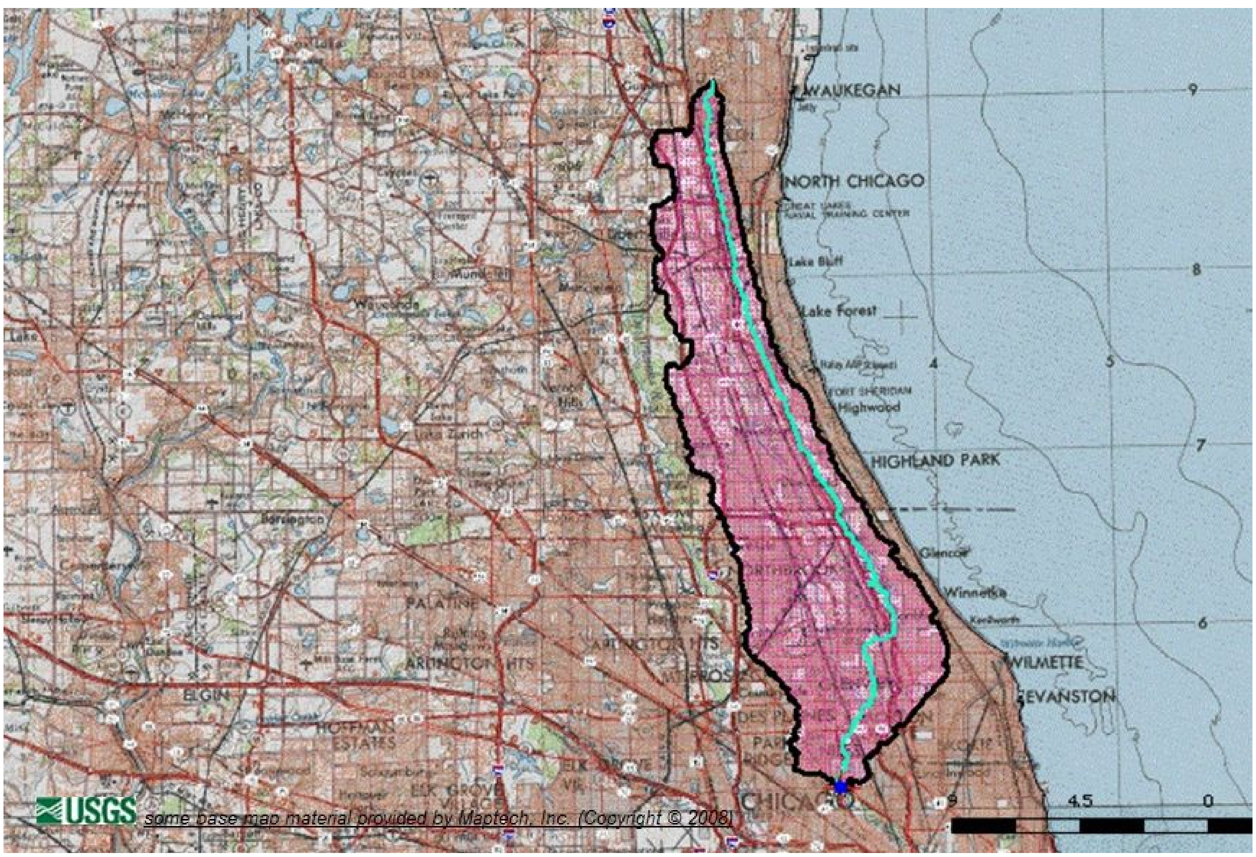

FIGURE E.7 Watershed of North Branch of Chicago River Upstream USGS Gaging Station at Niles, Illinois

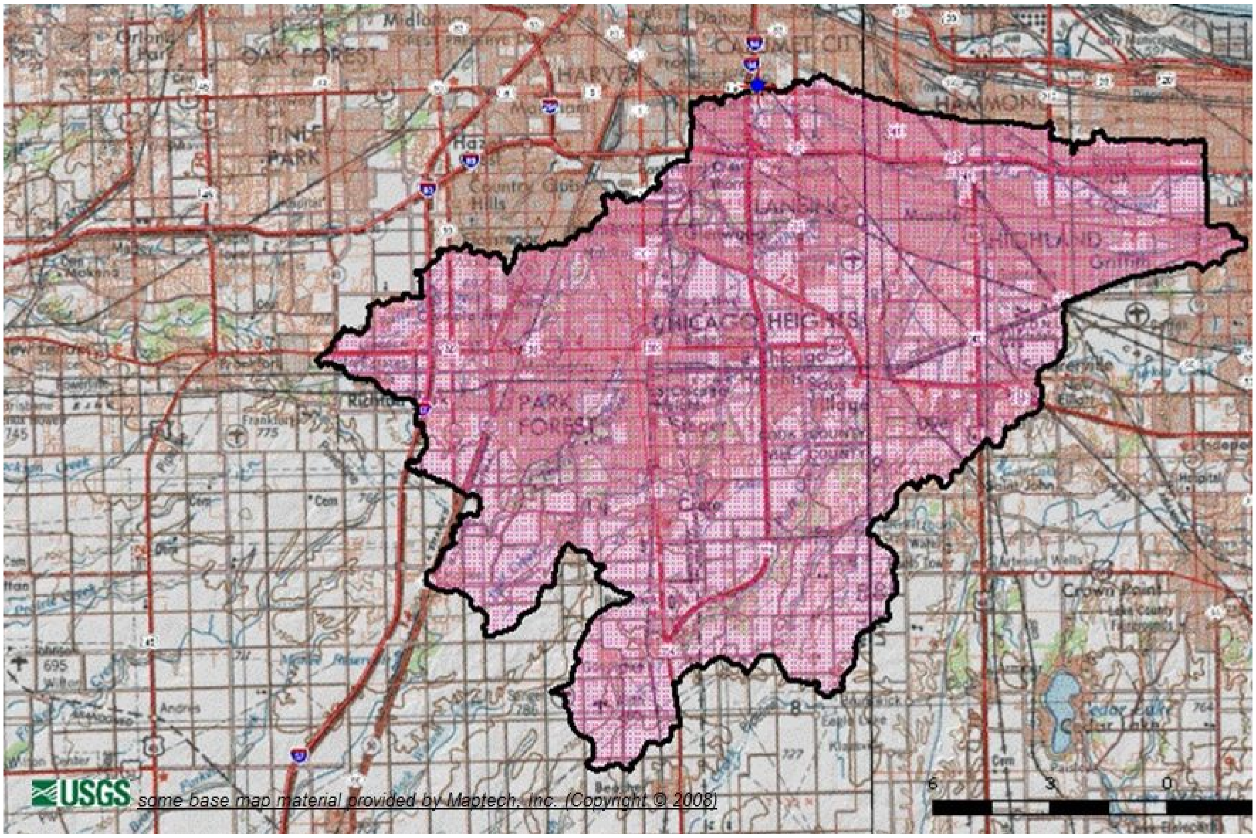

FIGURE E.8 Watershed of Little Calumet River Upstream USGS Gaging Station at South Holland, Illinois

TABLE E.8 Land Use for Chicago River North Branch (data for USGS gage #5536000 at Albany Avenue, Chicago, Illinois)

5536000		1992	2001	2006
2001&2006 NLCD codes		***1992***	***2001***	***2006***
11	Open Water	897	716	681
21	Developed, Open Space	8090	14244	14549
22	Developed, Low Intensity	13182	25719	25827
23	Developed, Medium Intensity	12526	9196	9324
24	Developed, High Intensity	7853	4023	4120
31	Barren Land (Rock/Sand/Clay)	4	7	46
41	Deciduous Forest	11821	4532	4281
42	Evergreen Forest	783	7	7
43	Mixed Forest	0	181	153
52	Scrub/shrub	0	136	109
71	Grassland/Herbaceous	1279	837	650
81	Pasture/Hay	3103	16	6
82	Cultivated Crops	2014	467	465
90	Woody Wetlands	1611	3404	3282
95	Emergent Herbaceous Wetlands	272	93	77
	In acreages			
	Impervious	20412	20904	21146
	Grassland	29561	34268	34424
	Forest	13462	8392	7994
	in %			
	Impervious	0.32	0.33	0.33
	Grassland	0.47	0.54	0.54
	Forest	0.21	0.13	0.13

TABLE E.9 Land Use for Little Calumet River (data for USGS gage #05536290 at South Holland, Illinois)

2001 and 2006 NLCD Codes		1992	2001	2006
11	Open Water	1853	1086	1042
21	Developed, Open Space	11808	12923	15152
22	Developed, Low Intensity	13995	46710	47915
23	Developed, Medium Intensity	22753	12964	14136
24	Developed, High Intensity	9688	4689	5029
31	Barren Land (Rock/Sand/Clay)	5	274	477
41	Deciduous Forest	707	10257	9690
42	Evergreen Forest	17657	171	153
43	Mixed Forest	3862	1738	1485
52	Scrub/shrub	5	1197	1136
71	Grassland/Herbaceous	3658	6599	5648
81	Pasture/Hay	10954	3903	3460
82	Cultivated Crops	30683	21769	19330
90	Woody Wetlands	3565	7542	7052
95	Emergent Herbaceous Wetlands	1017	390	506
	In acreages			
	Impervious	28720	31318	33145
	Grassland	77836	80221	79528
	Forest	25652	20672	19537
	in percentage			
	Impervious	0.22	0.24	0.25
	Grassland	0.59	0.61	0.60
	Forest	0.19	0.16	0.15

Tables E.8 and E.9 show that the impervious area increased by 1% and 3% in the upper North Branch of the Chicago River and the Little Calumet River, respectively, in a 14-year period from 1992 through 2006. Figures E.9 through E.11 show the land use for the CAWS basin in 1992, 2001, and 2006, respectively.

The historical land use data show that the land cover in the CAWS basin in the past couple of decades has not changed significantly. In addition, the coverage and strictness of stormwater management ordinances have grown continuously in the CAWS basin since the first ordinance promulgated by the MWRDGC in 1972. By 1986, the State of Illinois had passed legislation that authorized northeastern Illinois counties to develop their own regional stormwater management programs. These stormwater management programs restricted the increase of peak runoff from the newly developed land or reconstructed pavement surfaces. The impact of the stormwater detention can be confirmed by analyzing the annual maximum series of the streamgage records at the gaging stations in the CAWS or surrounding watersheds. A recent USGS study (Over and Su 2012) attempted to correlate the time frame of county-wide ordinance to the observed trends in the flood-peak records. The flood peaks did not show definitive increase in the past two decades.

In addition to the land use change and implementation of stormwater management ordinances, the hydrology of the CAWS basin may also be affected by major flood control projects, climate change, and green infrastructure implementation.

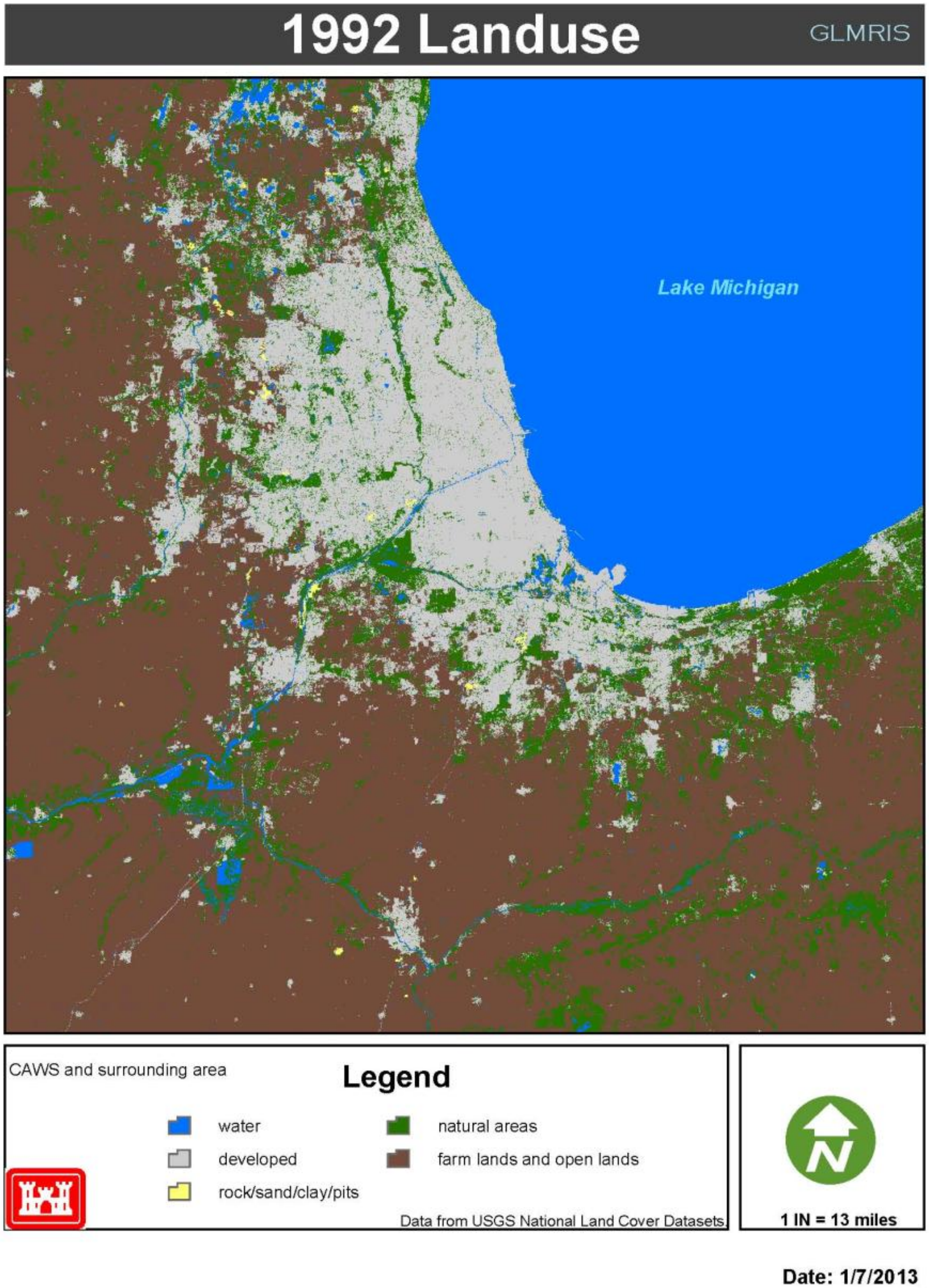

FIGURE E.9 Land Use in CAWS Basin for 1992

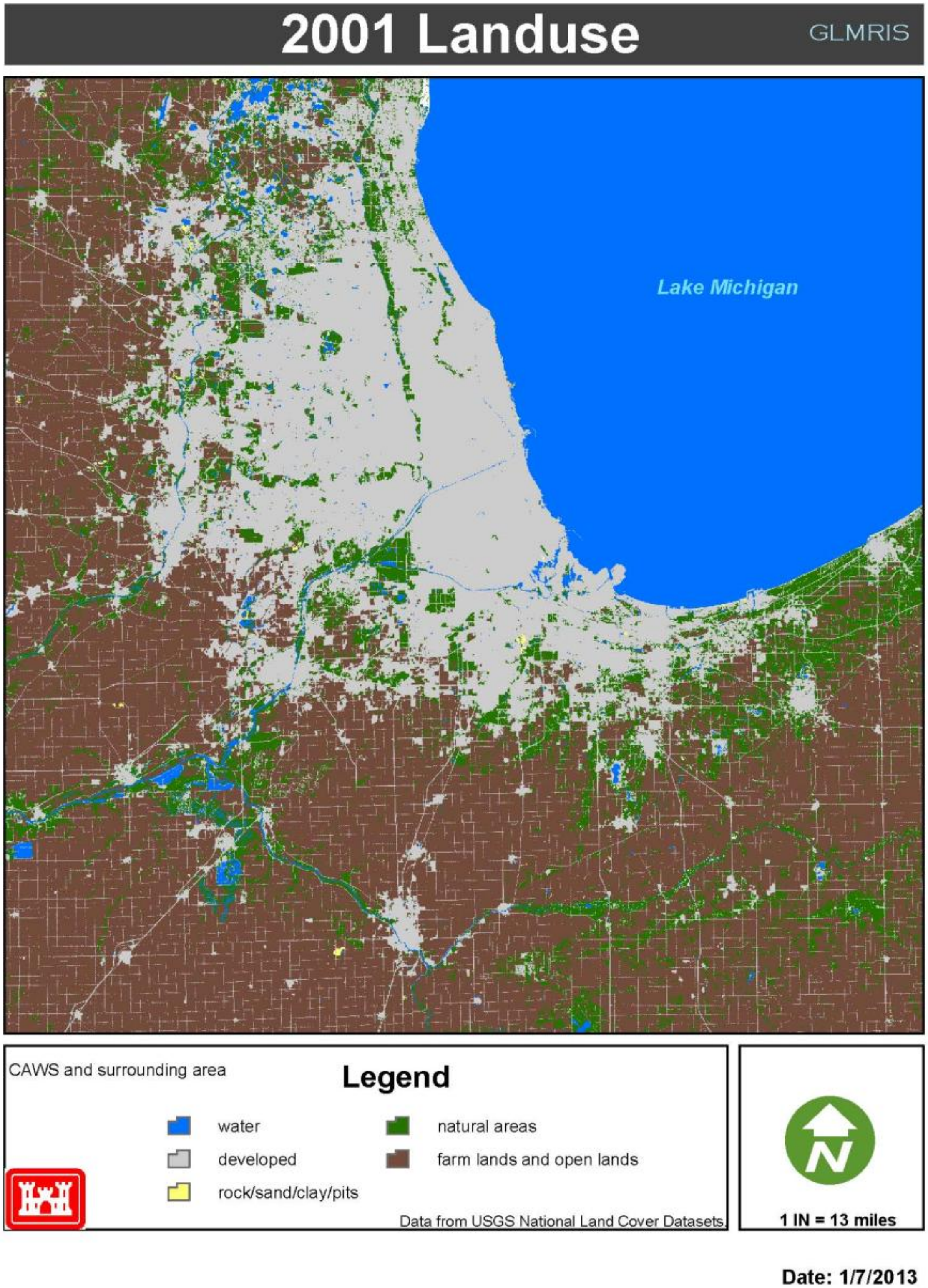

FIGURE E.10 Land Use in CAWS Basin for 2001

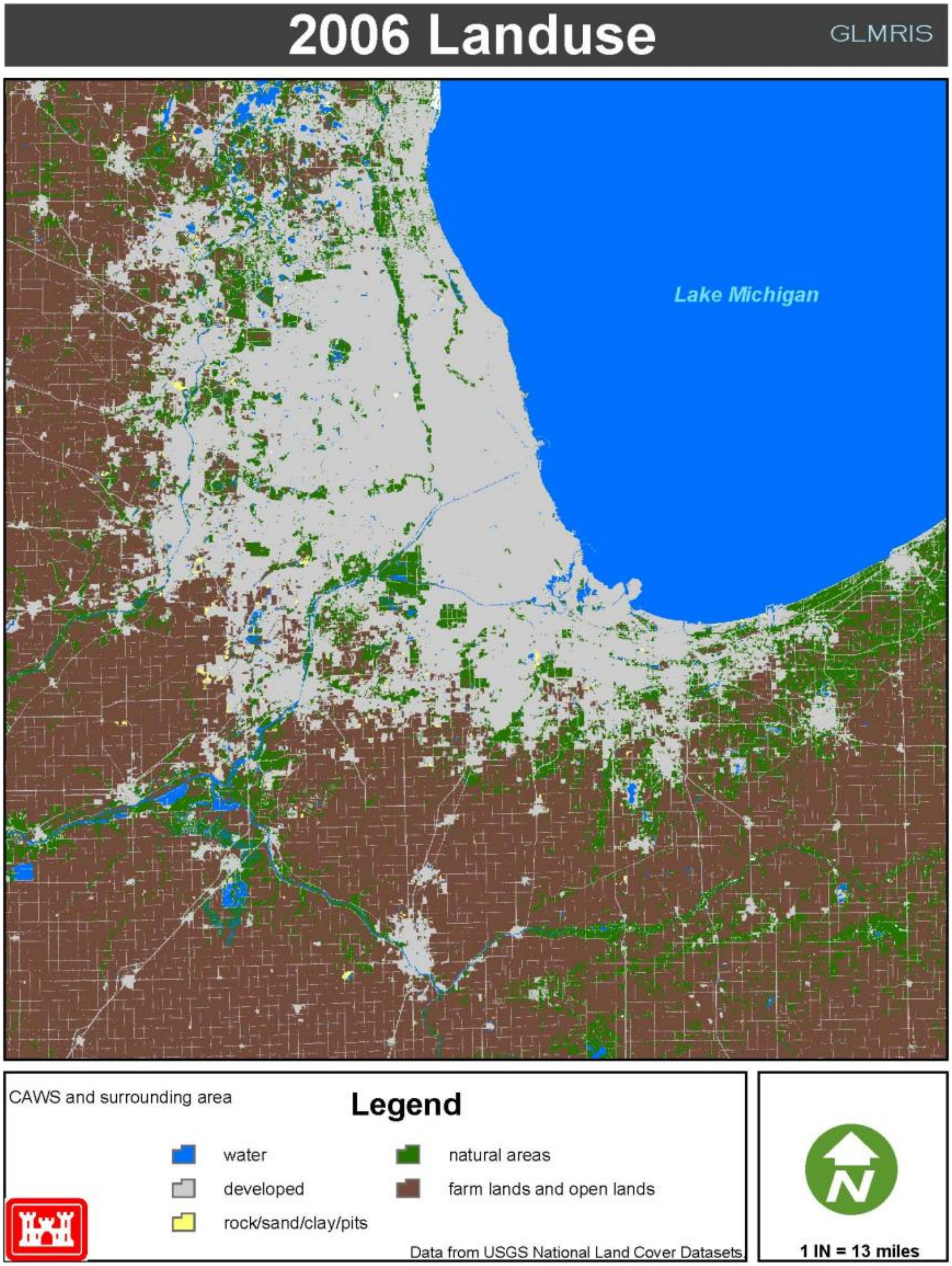

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FIGURE E.11 Land Use in CAWS Basin for 2006

E.6.2 Flood Control Projects

Between the mid-1980s and 2006, the MWRDGC completed three TARP tunnel systems: the O'Hare, Mainstream and Des Plaines, and Calumet systems. The main function of these tunnel systems was to reduce the frequency of CSOs. As part of the TARP plan, an excavated reservoir is linked to each TARP tunnel system. The small O'Hare reservoir has been in operation since 1998. The Thornton reservoir in the Calumet TARP system is scheduled to be completed in 2015, and the McCook reservoirs in the Mainstream and Des Plaines TARP system will be completed in 2017 and 2029 for stage 1 and stage 2, respectively. The storage capacity of these reservoirs has been provided in a previous section. The purposes of these TARP reservoirs consist of further CSO containment and flood risk management. During significant flood events the reservoirs can alleviate the flood stages on the CAWS. The availability of these reservoirs is the most significant factor affecting the hydrology and hydraulics during the flood events in the CAWS basin in the future. Therefore, the reservoirs were included in the modeling for the baseline and future conditions.

E.6.3 Climate Change

In performing hydrologic analyses for the synthetic events in the GLMRIS area, there are two choices: *ISWS Bulletin 70* and *NOAA Atlas 14*. Although the precipitation depth-duration-frequency curves presented in *NOAA Atlas 14* were developed by including more recent precipitation data from the precipitation gaging stations than the dataset used in *ISWS Bulletin 70*, the precipitation depths from *Atlas 14* are slightly lower. For the conservative and consistent reasons, the precipitation information provided in *ISWS Bulletin 70* was used in developing the synthetic rain events for GLMRIS. The ISWS acknowledged that the hydrologic modeling community has a strong interest in having an updated *Bulletin 70*, but this large effort could not start without committed funds. At the time this report is being written, the ISWS does not have a firm plan for revising *Bulletin 70* in the future.

As part of the analysis in the *NOAA Atlas 14*, the trends in the historical record in the mean and variance of the annual maximum series were examined. These statistics were used in producing new precipitation frequency estimates. These analyses for the Ohio River Basin and its surrounding states were included in Appendix 3, "Trend in volume 2 of Atlas 14 publication" (NOAA 2004). NOAA found that historically both the increase and decrease of the trend in a small proportion of observing stations were seen. In other words there is little spatial coherence.

Given that both ISWS and NOAA have neither published new precipitation DDF including more recent precipitation data nor qualitatively confirmed the potential climate change effect on precipitation, adjustment of precipitation for the future condition is not warranted at this point.

E.6.4 Green Infrastructure

Green infrastructures have been implemented in the City of Chicago and its surrounding suburban municipalities. These infrastructures include green roofs (i.e., roof-top gardens), rain barrels, bioswales, pervious sidewalk pavements, and the like. It is expected that the implementation of these technologies would continue reducing the storm runoff and improving the quality of water reaching the CAWS. Acceding to the GLC's basin separation study, 80 million gallons of green infrastructure storage will be added each year through application of the current ordinance requirement of capturing the first 0.5 in. of runoff (HDR 2012). The effect of these green infrastructures is more than just converting impervious areas to pervious areas. For instance, many of these green infrastructures would have different runoff response from that of the grass areas in the CAWS basin. Often the green infrastructures would not have dominant evapotranspiration to reduce the interflow that contributes to the sewers or waterway. At this time numerical models are not available to accurately quantify its effect on the reduction of flood peak discharge or flood stage; that is, the computed effects will easily be masked by the noises of the model uncertainties.

E.6.5 Floodplain Regulation

The State of Illinois, the State of Indiana, and the City of Chicago have not indicated there would be any regulatory changes in the future. Therefore, it is assumed that the existing regulations will be effective when the basin separation project is implemented. In addition, the federal (FEMA) requirements on the floodplain mapping for the 100-year event, that is, the base level flood (BLF), will continue without modifications.

E.6.6 Summary of Future Condition

In the future, climate change might increase the runoff for severe storm events; the land use might or might not affect the runoff owing to stormwater management regulations; and the implementation of green infrastructures might reduce the storm runoff. However, because of the lack of matured scientific research and municipal planning information beyond, say, 5 years, development of new hydrologic models taking into account these potential factors will bring little value to the project at this time because of the large uncertainties associated with various assumptions. That said, the assumptions of the future condition will be concluded by the statement, "the GLMRIS project takes into account the effect of Thornton and McCook stage-1 reservoirs in the hydrologic analysis for the baseline condition, and it includes the additional effect of the McCook stage-2 reservoir in the hydrologic analysis for the future condition. Regarding the potential or continued changes in climate, land use, and implementation of green infrastructures in the future, only qualitative discussions can be provided, and it is assumed in the current study that the effects induced by these factors are quantitatively undeterminable with acceptable confidence or would be mostly offset amongst themselves."

E.7 MODELING RESULTS WITH NO PROJECT

E.7.1 Critical Duration

The CAWS model was run for the 100-year event for both the existing and future conditions. In most reaches of the CAWS, the highest water levels corresponded to the 24-hour event. The maximum water levels on the CAWS for 3-, 12-, 24-, and 48-hr events are summarized in Enclosure A. Figures 1 through 6 show the maximum water levels on various reaches of CAWS for the future condition, and Figures 7 through 12 show the maximum water levels on various reaches of CAWS for the existing condition. For various reasons, 24 hr is chosen to be the critical duration for the CAWS.

E.7.2 Maximum Water Levels on CAWS

The simulated maximum water levels on the CAWS from 1- through 500-year events were summarized in Enclosure B. The information is used by the economic team to model damages for the overbank and basement flooding for the no-project condition. It is also used for setting the target for flood mitigation for the with-project conditions.

Figures 1 through 6 show the modeling results for the baseline condition. Figure 1 shows the maximum water levels on the CSSC, the South Branch of the Chicago River, and the North Branch of the Chicago River. Figure 2 shows the maximum water levels on the CSSC, Cal-Sag Channel, North Little Calumet River, and Calumet River. Figure 3 shows the maximum water levels on the West Branch of the Grand Calumet River. Figures 4 through 6 show the stage hydrographs for the Chicago River at the CRCW, the Calumet River at the O'Brien Lock and Dam, and the NSC at the WPS, respectively. Figures 7 through 12 show the modeling results for the corresponding future condition. Figures 13 and 14 show the difference of the maximum water levels on the main CAWS for the 500-year event for the baseline condition with the lake level at 580 ft NAVD versus 583 ft NAVE. Figures 17 and 18 are the inundation maps for the 500-year event for the baseline and future conditions, respectively. Most reaches of CAWS have very narrow or none floodplains; the water level in the waterway is controlled to stay in the main channel during rain events. The areas usually at flood risk are limited to lower Wacker Drive, the Union Station rail tracks, and some small low-lying areas. To avoid flooding in the Chicago metropolitan area, the sluice gates and lock gates at the lakefront controlling works are opened to allow floodwater to enter Lake Michigan. In addition, the gates at the lakefront controlling works are opened at the same threshold for both the baseline and future conditions. Therefore, Figures 17 and 18 do not show large inundation areas, nor do they show noticeable differences of the inundation area between the baseline and future conditions.

As a sensitivity analysis, the estimated effect of the occupancy of McCook reservoir prior to the design rain event on the maximum river stage on the Chicago River near Wolf Point (RM 325.54) where it confluences with NBCR and SBCR in downtown Chicago for the 500-year event for the future condition is given in Table E.10.

TABLE E.10 Estimated Occupancy of McCook Reservoir

McCook Reservoir Fill Prior to the Design Rain Event (%)	Stage on the Chicago River in Downtown Chicago (ft NAVD)
0	582.77
65	583.28
100	583.54

The sharp drops of the stages in Figures 4, 5, 10, and 11 in Enclosure B for larger events are results of sluice gate and lock gate operations at lakefront controlling works. When water levels on the waterway reach predefined thresholds per waterway operations procedure, sluice gates and lock gates open to reverse floodwater to Lake Michigan. The "post-shift" stage rise for the larger storms is due to the gate closure before majority runoff is cleared from the waterway system. In the real world, the gates would be closed as soon as waterway operation personnel believe that stage would not rise to pass the threshold again during the storm to minimize the amount of reverse flow to the lake (water quality impact on Lake Michigan). As long as the post-shift peak on the falling limb of the hydrograph does not surpass the maximum peak, it is acceptable to the economic analysis.

Since the model does not have a "look-ahead" capability, water is allowed to leave the downstream end of the waterway system (Lockport Powerhouse and sluice gates) by opening the flood gate in anticipation of runoff from a storm (i.e., canal drawdown). However, the navigation requirement does not allow the water level on the CAWS at RM 303 to fall below −4 ft CCD. Thus, the gate at the Lockport Powerhouse must close once the above threshold at RM 303 is reached. This alternate open/close gate sequence at Lockport produces the wave pattern of water level on the waterway after the storm runoff diminishes in the system, as shown in Figures 4, 5, 6, 10, 11 and 12 in Enclosure B. Since the modeling interest is peak stages on the waterway through a design storm, the unrealistic oscillation of stage under the "normal" waterway condition causes no concern in the modeling effort.

E.8 MODELING RESULTS WITH HYDROLOGIC SEPARATION PROJECT

The hydrologic models developed for the baseline and future conditions without GLMRIS are discussed in Sections E.5 and E.6. These models were not changed to analyze the hydraulics of the CAWS if one or more hydrologic separation barriers were to be constructed in the waterway. The hydrologic separation structures include two basic categories: (1) closure of the existing water control structures, and (2) construction of new physical barriers. At the existing structures the sluice gates in the dam or lock gates were set to zero opening regardless of the water level condition on the river and lake side of the structure, and the crest of the structure was extended to above the highest expected local water elevation in the HEC-RAS model. Simple inline dams that have a non-overtopping crest elevation at potential hydrologic separation locations were created in the HEC-RAS model to represent the new barrier structures.

The purpose of the hydrologic and hydraulic modeling is to provide the stage and discharge information for the CAWS under different hydro-meteorological conditions. The selection of final set of separation alternatives for GLMRIS is based on many evaluation criteria other than flood risk management. The details of development and evaluation of separation alternatives are documented in the plan formulation section of the report.

The simulated maximum water levels on the CAWSs from 1- through 500-year events were summarized in Enclosure B. The information is used by the economic team to model damages for the overbank and basement flooding for the with-project condition. It is also used for sizing the hydraulic components for flood mitigation due to project alternatives.

E.8.1 Site Screening

The physical barrier can be constructed on the waterway as high as it needs to be to block flows through the river channel or floodplain. However, flow can bypass the barrier and a path can be formed under certain circumstances that make the barrier ineffective. Various probable scenarios of bypass paths are discussed below.

1. *Divided Channels*. CAWS is divided into multiple channels at certain locations. If a physical barrier is placed on one channel, the other channel will form a bypass connection. The North Branch of the Chicago River and the North Branch Canal near Goose Island is an example. This is the most obvious type of bypass, and it can hardly be missed by visual inspection of the hydrographic maps

2. *Bypass Tributary*. A tributary system connects to the CAWS at two points. If a physical barrier is placed on the CAWS somewhere between these two points, a permanent bypass connection will be formed. East Stony Creek/West Stony Creek and Midlothian Creek/Midlothian diversion culvert are two examples.

3. *Connecting Watersheds*. Two tributaries connect to the CAWS at two points. During large storm events the upstream watershed may be connected by overbank flood waters. If a physical barrier is placed between the outlets of these two tributaries, an episodic connection may be formed. Natalie Creek/Midlothian Creek is an example.

4. *Spillover*. A separate stream runs in parallel with the CAWS. During large storm events the stream flow can go overbank and spill over to the CAWS. The Des Plaines River/CSSC is an example.

5. *Flanking*. Floodwater can move around the physical barrier if the tie-in high ground is not available or the barrier is not high enough. The area near the Bubbly Creek and the South Branch of the Chicago River is an example.

6. *Sewer Connection*. Storm or combined sewers discharge stormwater or CSO to the CAWS through a few hundred outfall pipes during wet periods. Most outfalls will be partially or fully submerged during the flood. If the flap gates are inadvertently left open, a bypass connection can be established through the sewer system.

7. *Groundwater Connection*. A moderate amount of water can seep through rock piles or rock fiche, which may become a bypass path for certain small ANS species.

8. *Water Purification Plant*. It is assumed that the water purification process will screen or kill any life form of the ANS.

9. *Waste Water Treatment Plant*. It is assumed that the sewer treatment process will kill any life form of the ANS.

Figure E.12 shows the schematic of the surface water connection types 1 through 5 that are considered in the site screening process.

Except for the scenario in which the physical barrier will be placed downstream from the Cal-Sag Junction, multiple barriers are required on the CAWS to separate watersheds to reduce the risk of ANS transfer. The combination of different locations of these barriers on the waterway can produce a large number of different hydraulic conditions. In this study two without-project conditions are considered: baseline (2017) and future (2029) conditions. The baseline condition includes TARP tunnels (1.82 BG), Thornton reservoir (7.9 BG), and stage-1 McCook reservoir (3.5 BG) in the CAWS basin. The future condition includes the stage-2 McCook reservoir (6.5 BG) in addition to the floodwater storage capacity included in the baseline condition. The total storage capacity of McCook reservoir will be 10 BG after stage-2 reservoir is completed.

The main purpose of site screening is to provide a general assessment of the impact of hydro separation on the water levels in the CAWS based on which the less impacting alternatives from the flood risk management perspective can be identified. It would be too laborious and technically unnecessary to screen various separation alternatives using a full set of rain frequencies. The 500-year/24-hr rain event for the future condition was chosen for screening various alternatives. However, all eight rain event frequencies for the baseline and future conditions were modeled for a couple of finally selected hydrologic separation alternatives for the economic analysis for flood damage based on HEC-FDA. Table E.11 provides the river station (RS) and brief description for the potential hydrologic separation locations on the CAWS.

Figure E.13 shows the locations of potential hydrologic separation on the map.

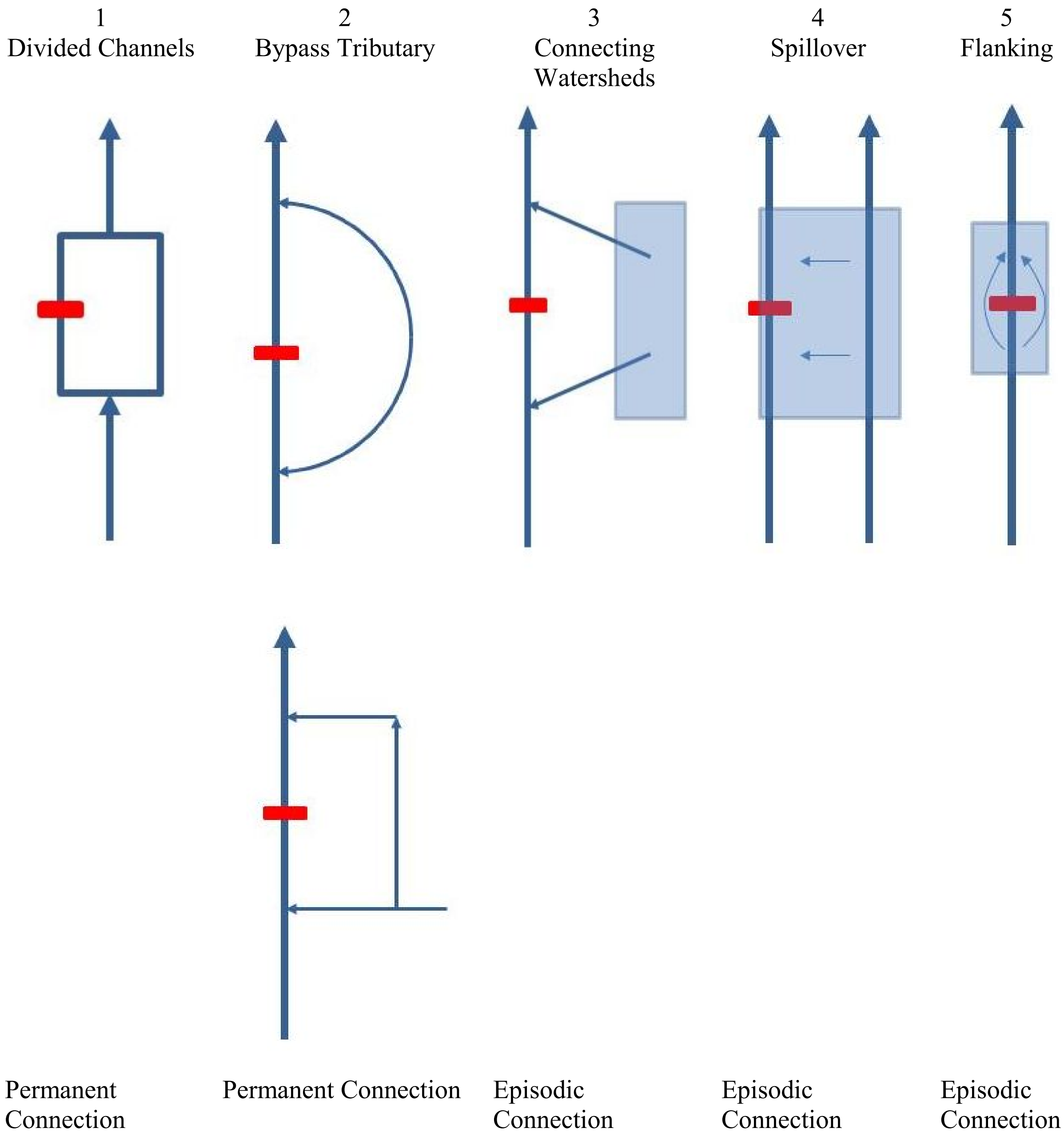

FIGURE E.12 Schematic of Bypass Connections

TABLE E.11 Potential Hydrologic Separation Locations on the CAWS

Separation ID	River Reach	Barrier Location (River Station in HEC-RAS)	Remarks
1	North Shore Channel	340.795/1008	WPS
1A	North Shore Channel	336.542/1112.5	North of O'Brien WRP outfall (RS 1113)
2	North Branch of Chicago River	333.05	South of NSC confluence (RS 333.11). Upper North Branch of the Chicago River flow and O'Brien WRP effluent go to lake.
3	Chicago River	327.12/1033	West lock gates at CRCW
3A	Chicago River	325.656/1134.5	Near Wolf Point
4	CSSC	316.01	East of Stickney WRP outfall (RS 315.81)
4A	South Branch of Chicago River	322.74	East of Bubbly Creek confluence (RS 321.5)
5	CSSC	302.33	Near the USGS streamgage in Lemont for diversion accounting
6	Cal-Sag Channel	319.25	West of Little Calumet River confluence (RS 319.6). Little Calumet river flows to lake.
6A	Cal-Sag Channel	315.89	West of Natalie Creek confluence (RS 315.91). Natalie Creek and Midlothian Creek water goes to lake. This separation requires an additional small barrier on Stoney Creek.
7	Calumet River	326.26/1183	O'Brien Lock and Dam
8	Little Calumet River North	321.00	At ACME bend near the Calumet WRP outfall (RS 320.92/321.28). Calumet WRP effluent goes to Lockport.
8A	Little Calumet River North	324.5	Near Bishop-Ford Expressway, i.e., I-94, Crossing (RS 324.5)
9	Little Calumet River South	16.37	Approximately 1,000 ft west of the Hart Ditch control structure included in the Little Calumet River tributary model
10	Grand Calumet River	4.21	Near the Hammond Wastewater Treatment Plant outfall, east of Columbia Avenue
10A	Grand Calumet River	0.815	Near east end of Storage Areas CR6 and CR7-1

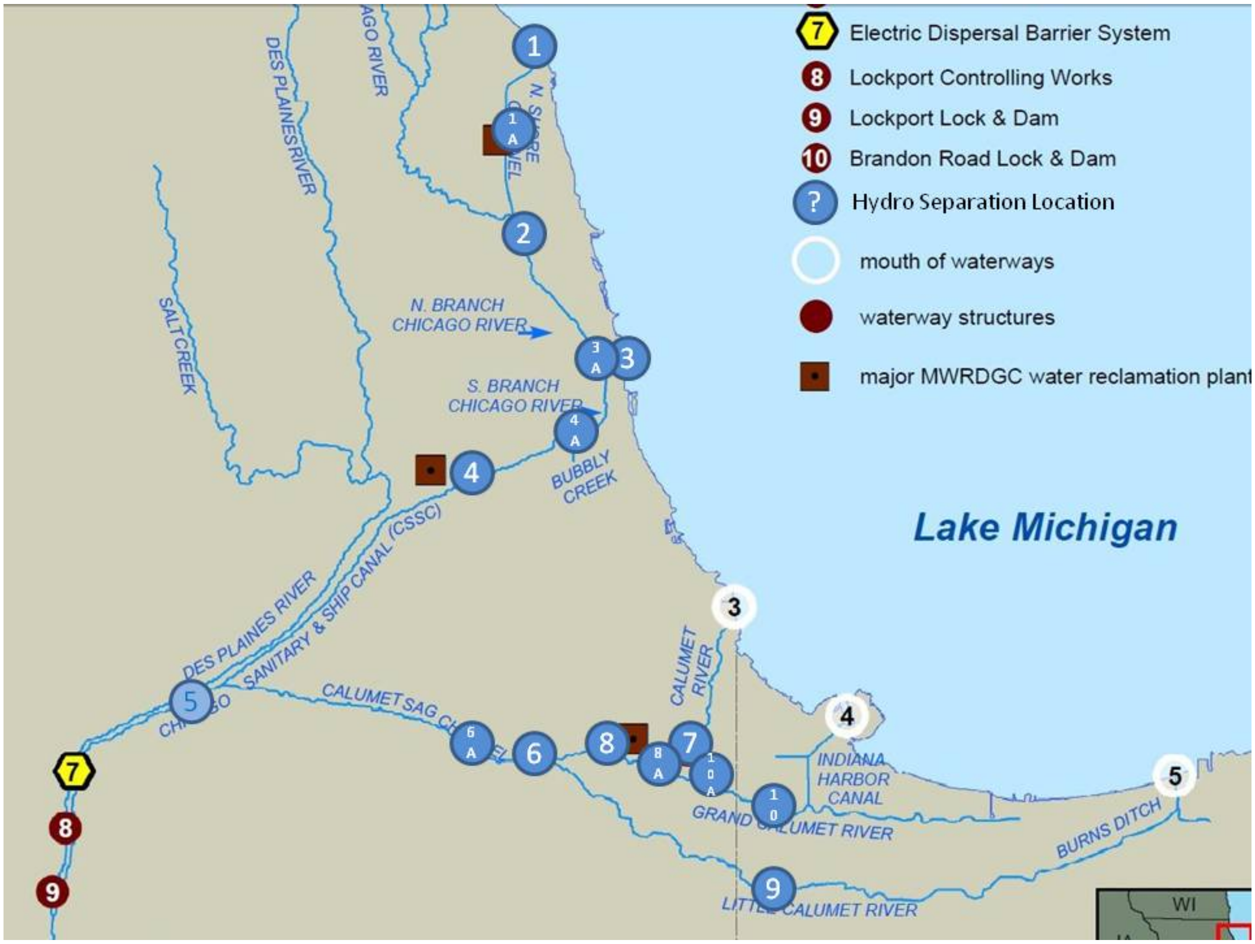

FIGURE E.13 Map of Potential Hydrologic Separation Locations

Table E.12 provides the scenarios in which the waterway would be modified by physical barriers to prevent ANS transfer to the maximum extent possible between the Great Lakes and Mississippi River watersheds. The alphanumerical identifiers in columns 2 through 6 in Table E.12 denote the barrier locations as given in Table E.11 and Figure E.13. The nomenclature was chosen arbitrarily to distinguish a number of different hydrologic separation scenarios. The full names are used to refer to the project alternatives in the final report so that there is no confusion between the nomenclature used for screening scenarios and project alternatives.

Table E.13 summarizes the scenarios of hydrologic separation and the reach of CAWS for which a physical barrier is required. The names of these scenarios were used as the plan IDs in the unsteady HEC-RAS modeling.

TABLE E.12 Scenarios of Hydrologic Separation on CAWS

Scenario	Barrier 1	Barrier 2	Barrier 3	Barrier 4	Barrier 5
A1 (Lakefront closure)	1	3	7	9	10
B1 (Lakefront closure; controlling works modified)	1	3	7	9	10
C1 (Lakefront closure; controlling works modified and Grand Calumet River blocked at CR6 and CR7-1)	1	3	7	9	10A
D1 (C1 but near Wolf Point on Chicago River)	1	3A	7	9	10A
E1 (B1 but near I-94 on Little Calumet River North)	1	3	8A	9	
A2 (North Branch of Chicago River near NSC confluence)	2*	3	7	9	10
B2 (NSC near O'Brien WRP)	1A	3	7	9	10
A3 (CSSC near Stickney WRP)	4	7	9	10	
B3 (South Branch of Chicago River near Bubbly Creek confluence)	4A	7	9	10	
C3 (Chicago Lock removed)	4	7	9	10	
D3 (Chicago Lock opens at 580)	4	7	9	10	
A4 (Little Calumet River near Calumet WRP)	1A	3	8	9	
A5 (Cal-Sag Channel near Little Calumet River confluence)	1A	3	6		
B5 (Cal-Sag Channel near Natalie Creek confluence)	1A	3	6A		
A6	2[a]	3	8	9	
A7	2[a]	3	6		
A8	4	8	9		
A9	4	6			
B9	4	6A			
A10	5				

[a] Based on modeling results for Scenario A2, barrier location 2 was dropped from further consideration. Scenarios A6 and A7 were not modeled.

TABLE E.13 Names of Hydrologic Separation Scenarios

Scenario	No. of Barriers	NSC	NBCR	Chicago River	SBCR	CSSC	Cal-Sag Channel	Little Calumet River-South	Little Calumet River-North	Calumet River	Grand Calumet River
A1	5	WPS		CRCW				Hart Ditch confluence		O'Brien	Columbia Ave.
B1	5	WPS		CRCW				Hart Ditch confluence		O'Brien (Modified 1)	Columbia Ave.
C1	5	WPS		CRCW				Hart Ditch confluence		O'Brien (Modified 2)	East of CR6 and CR7-1
D1	5	WPS		Wolf Point				Hart Ditch confluence		O'Brien (Modified 2)	East of CR6 and CR7-1
E1	4	WPS		CRCW				Hart Ditch confluence	Bishop-Ford Highway		
A2	5		NSC confluence	CRCW				Hart Ditch confluence		O'Brien	Columbia Ave.
B2	5	O'Brien WRP		CRCW				Hart Ditch confluence		O'Brien	Columbia Ave.
A3	4			(Lock gates open all the time)		Stickney WRP		Hart Ditch confluence		O'Brien	Columbia Ave.
B3	4			(Lock gates open all the time)	Bubbly Creek Confluence			Hart Ditch confluence		O'Brien	Columbia Ave.
C3	4			(Chicago Lock gates removed)		Stickney WRP		Hart Ditch confluence		O'Brien	Columbia Ave.
D3	4			(Lock gates open at 580)		Stickney WRP		Hart Ditch confluence		O'Brien	Columbia Ave.
A4	4	O'Brien WRP		CRCW				Hart Ditch confluence	Calumet WRP		
A5	3	O'Brien WRP		CRCW			Little Calumet River Confluence				
B5	3	O'Brien WRP		CRCW			Natalie Creek confluence				
A8	3					Stickney WRP		Hart Ditch confluence	Calumet WRP		
A9	2					Stickney WRP	LRC Confluence				
B9	2					Stickney WRP	Natalie Creek confluence				
A10	1					Lemont gaging station					

The NSC has a very small conveyance, which cannot efficiently carry all the floodwater from the North Branch of the Chicago River upstream from the junction of the NSC with the North Branch of the Chicago River to the mouth of the NSC near Wilmette. Figure E.14 shows the maximum water surface profiles on the NSC for all modeled scenarios. The dark red curve (Scenario 2) to the right of the profile plot in Figure E.15 also shows a significant rise. Based on the modeling results for Scenario A2, barrier location 2 was dropped from further consideration, and thus Scenarios A6 and A7 in Table E.12 were not modeled.

Figure E.15 shows the maximum water levels on the Chicago River system of the CAWS for the 500-year/24-hr event for the future condition for selected scenarios. The grey dashed line in the figure is the result for the no-project condition; the red line at the top is the Lakefront Hydrologic Separation Alternative; and the light green line at the bottom is the Mid-System Hydrologic Separation Alternative. The maximum water levels on the CAWS for the two finally selected hydrological separation scenarios approximately bound the water levels for other scenarios. The Lakefront Hydrologic Separation Alternative (Scenario E1) has the most significant adverse effect on the water level on the CAWS that requires mitigation for flood risk management. On the other hand, the Mid-System Hydrologic Separation Alternative (Scenario B9) causes the water levels on the CAWS to be even lower than the existing condition.

Figure E.16 shows the maximum water levels on the Calumet River system of the CAWS for the 500-year/24-hr event for the future condition for selected scenarios. Similarly, the maximum water levels on the CAWS for the two selected hydrologic separation alternatives are near the upper and lower ends of the water level range for various scenarios as well.

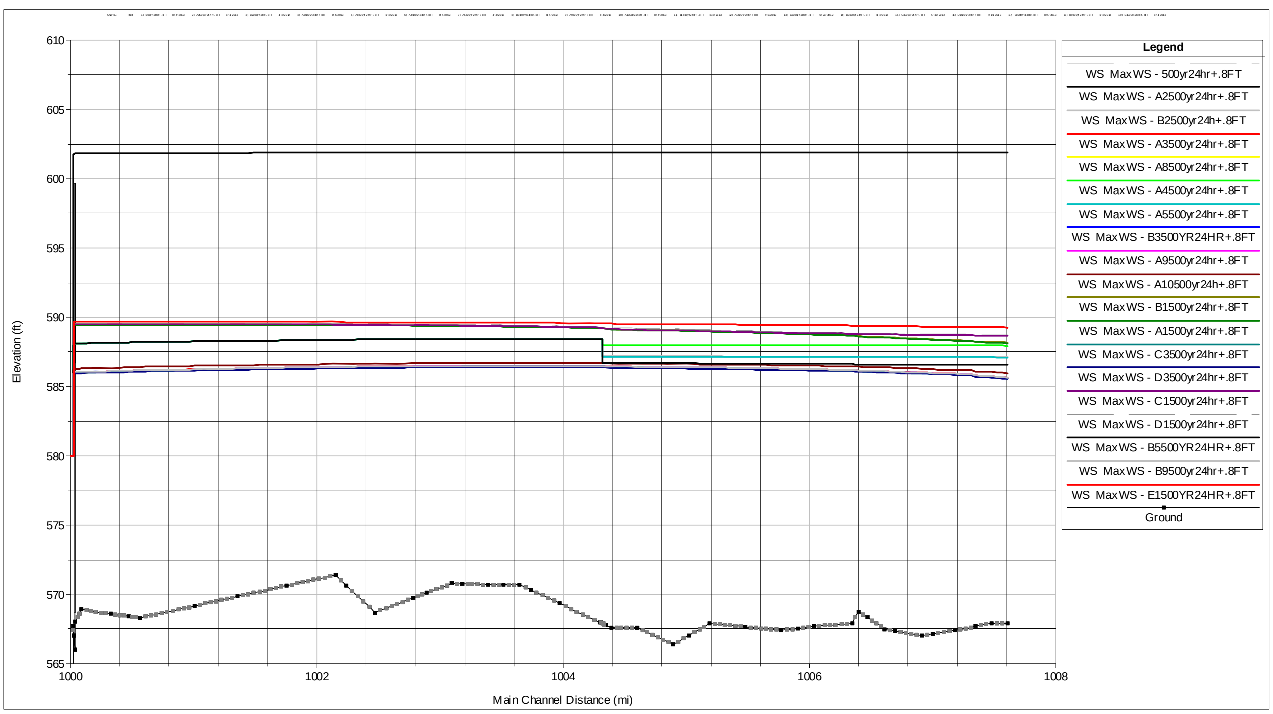

FIGURE E.14 Comparison of 500-Year Maximum Water Levels on NSC for the Future Condition

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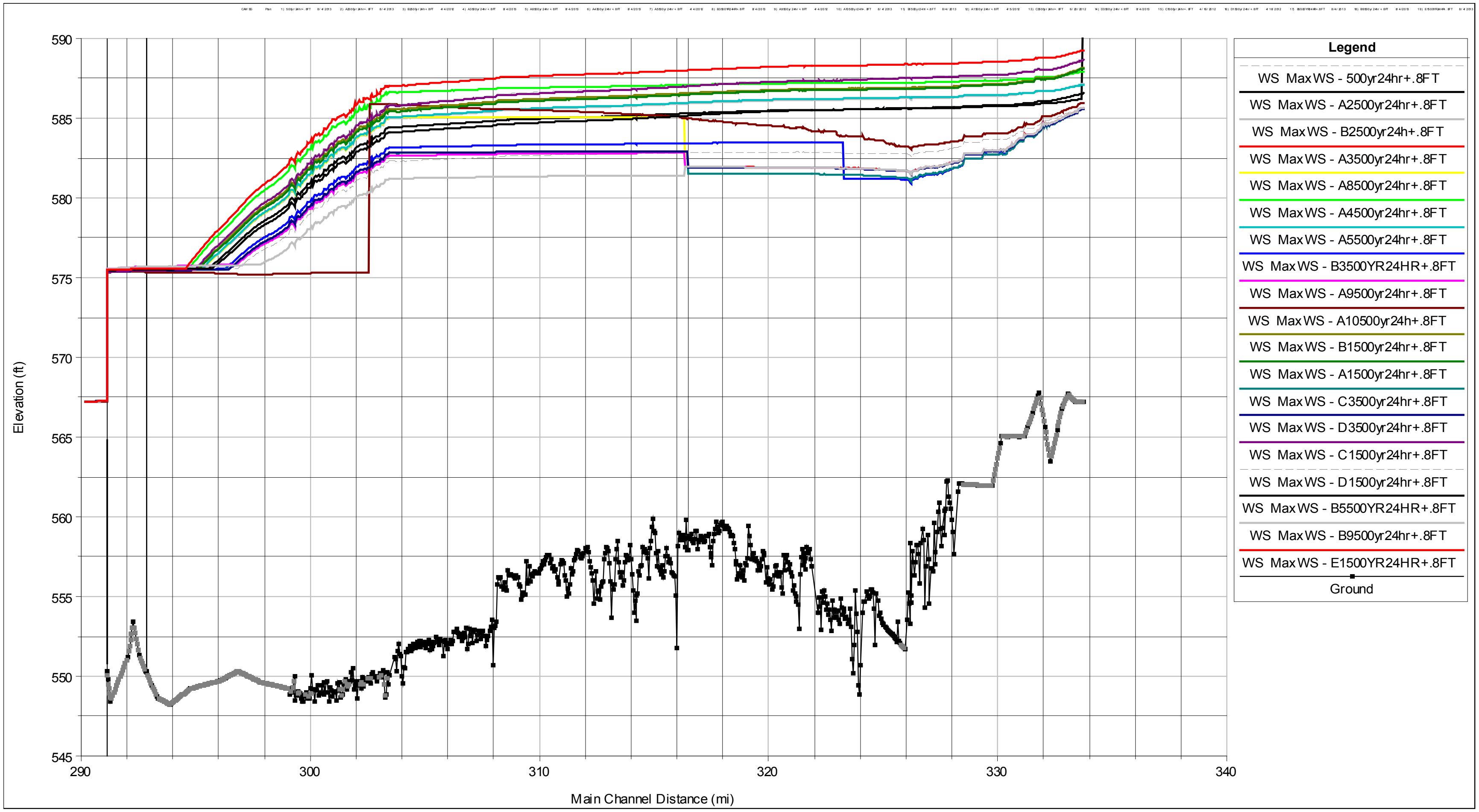

FIGURE E.15 Comparison of 500-Year Maximum Water Levels on the CSSC, South Branch of the Chicago River, and North Branch of the Chicago River for the Future Condition

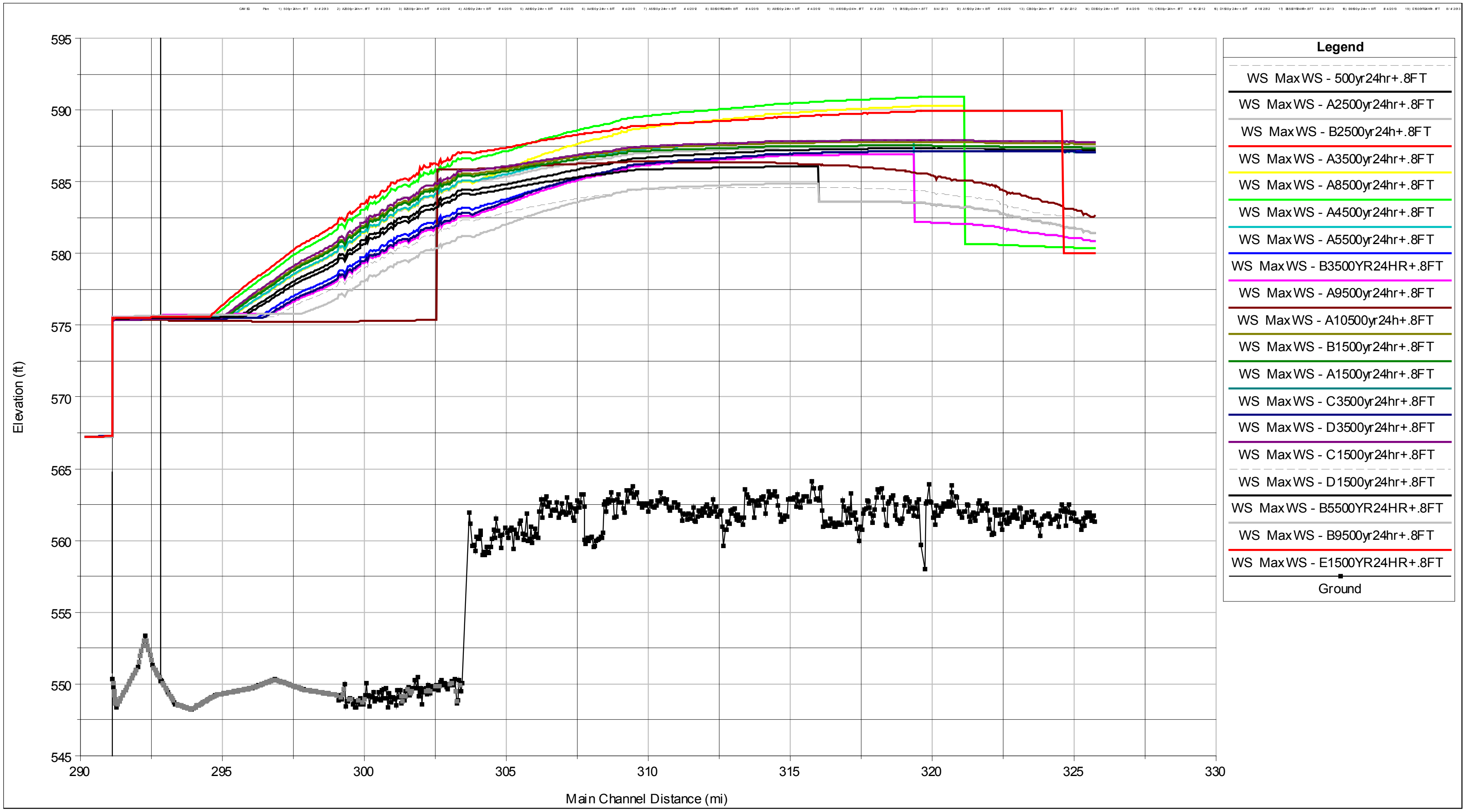

FIGURE E.16 Comparison of 500-Year Maximum Water Levels on the CSSC, Cal-Sag Channel, and North Little Calumet River for the Future Condition

E.8.1.1 Location on CSSC or South Branch of the Chicago River (Scenario A3 versus B3)

The hydrologic separation location for the Calumet River system of CAWS is the same for Scenarios A3 and B3. However, the barrier is located on the lake side of the Stickney Water Reclamation Plant (WRP) outfall on the Chicago River system for Scenario A3, whereas the barrier is located on the lakeside of Bubbly Creek confluence for Scenario B3.

The topography near barrier location 4A is generally lower than that near location 4 (see Figure E.17). Scenario B3 containing barrier 4A needs to reach farther out tying back to high ground. The grey dashed curve in Figure E.15 shows the future without project condition. Scenario B3 also requires larger flood mitigation facilities.

A significant flood event occurred in the CAWS basin in April 2013. During the event the lock gates at the Chicago Lock had to be opened to discharge floodwater in the CAWS to Lake Michigan. Figure E.18 shows a snapshot of the water levels on the Chicago River system of the CAWS soon after the lock gates were opened. The water surface elevation profile shows that the water level at Stickney (RS 315.8) was higher than that at Western Avenue (1.2 mi from Bubbly Creek confluence at RS 321.5), and the flow divide was near Stickney WRP outfall during the flow reversal.

Figure E.19 shows the comparison of the 500-year maximum water levels on the CSSC, South Branch of the Chicago River, and the North Branch of the Chicago River for the future condition. The results indicate that the location at Stickney would perform slightly better than Bubbly Creek confluence from the flood risk management perspective.

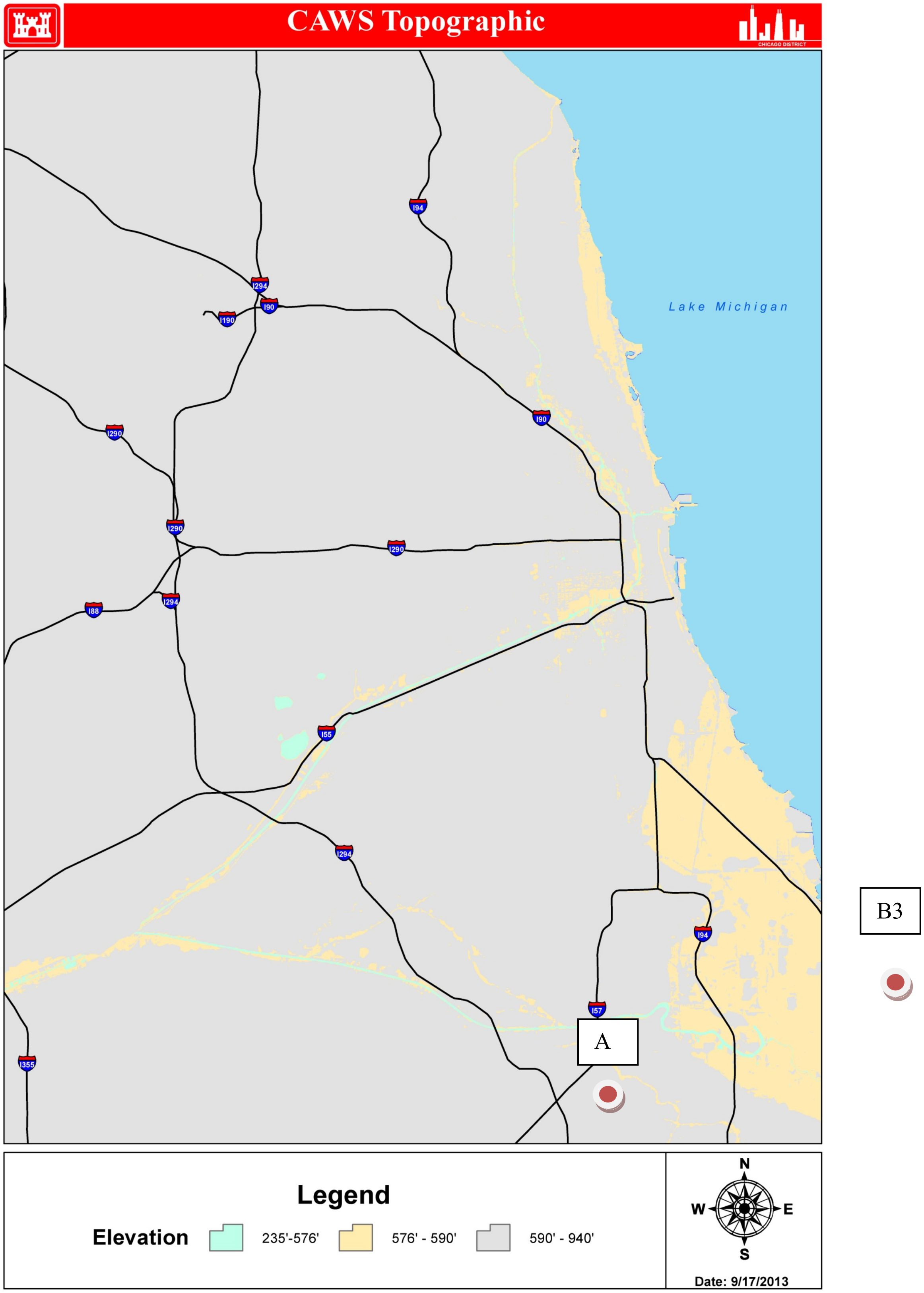

FIGURE E.17 Topographic Map of the CAWS Basin

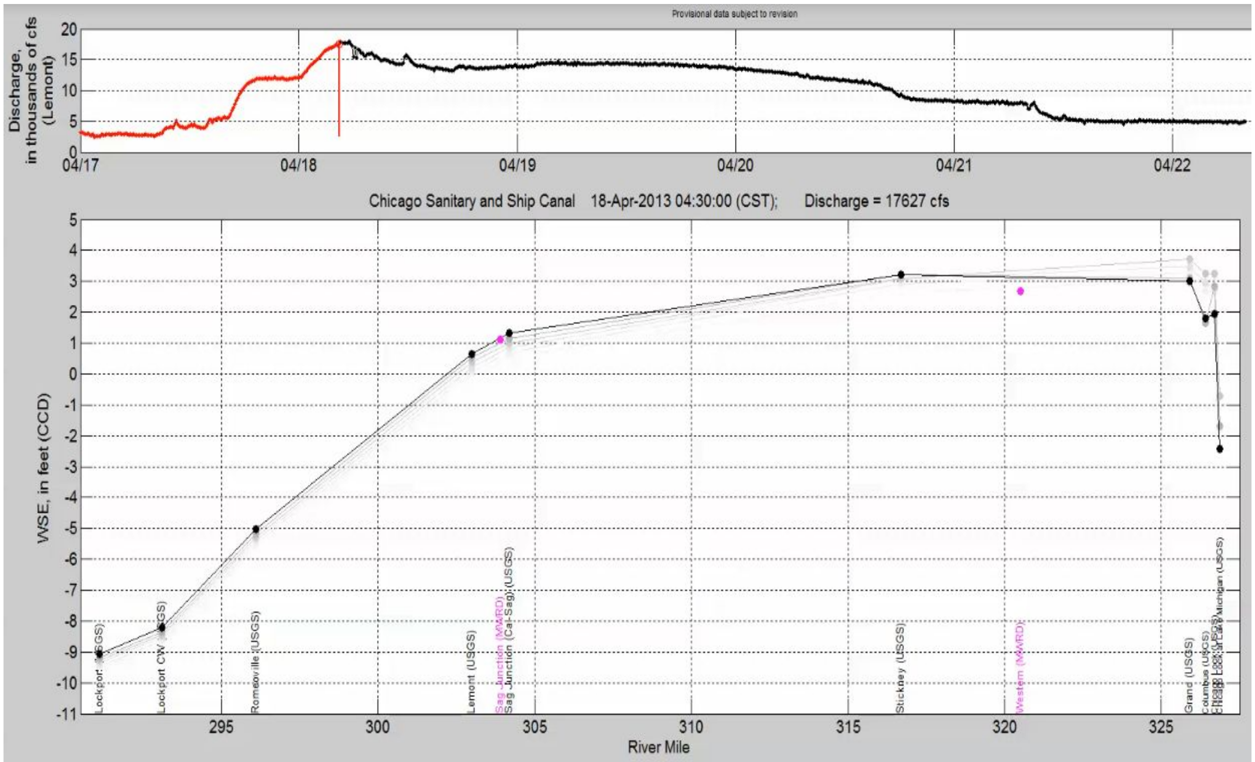

FIGURE E.18 Water Surface Profile on the Chicago River System during April 18, 2013, Flood

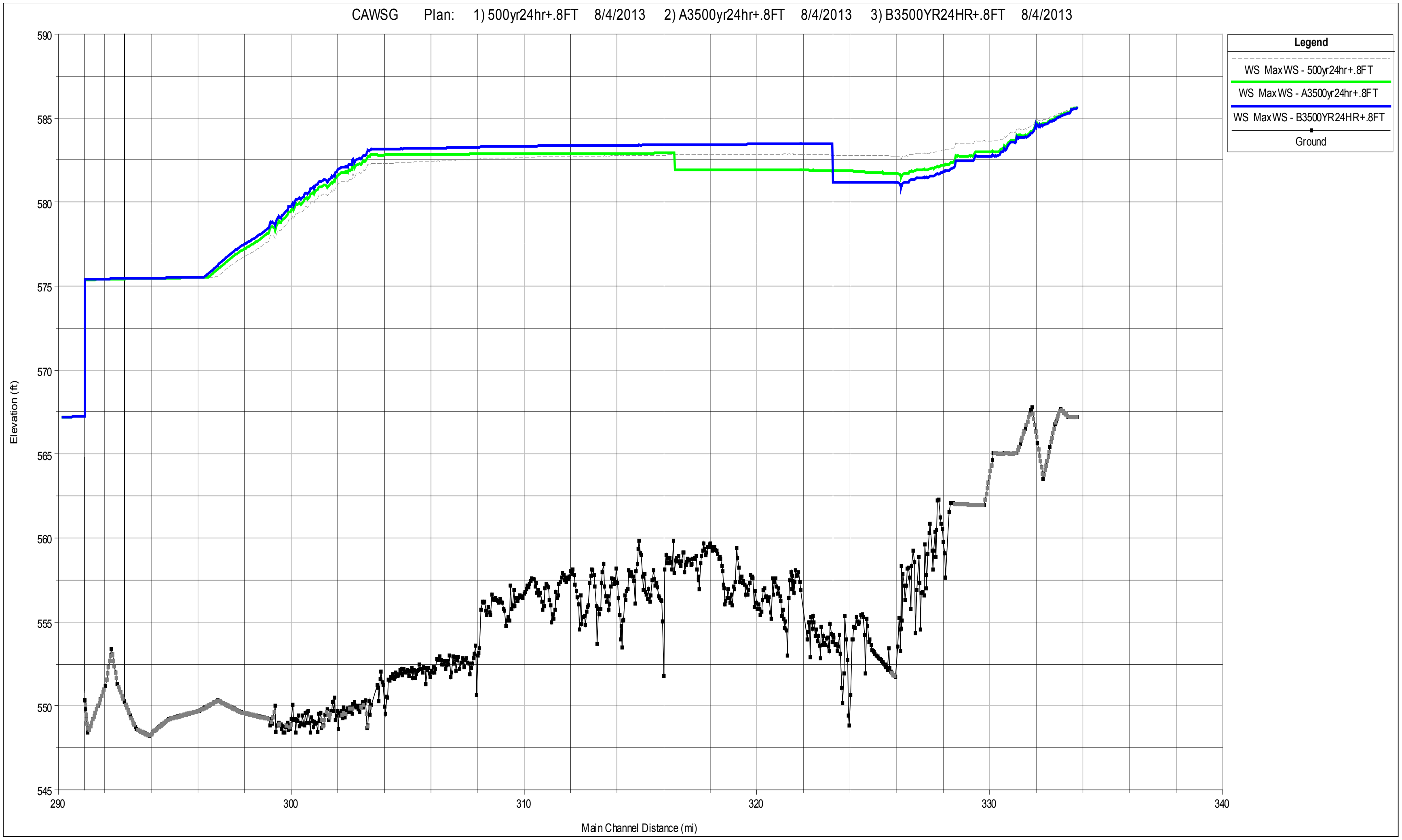

FIGURE E.19 Comparison of 500-Year Maximum Water Levels on the CSSC, South Branch of the Chicago River and North Branch of the Chicago River for the Future Condition (Location on CSSC or South Branch of the Chicago River)

E.8.1.2 Location near O'Brien Lock and Dam (Scenario B1 versus E1)

The hydro separation location on the Chicago River system of the CAWS is the same for Scenarios B1 and E1, but the location is different on the Calumet River system. Scenario B1 uses the existing O'Brien Lock and Dam as one barrier and requires an additional barrier on the Grand Calumet River to separate the Great Lakes and Mississippi River basins. Scenario E1 moves the barrier less than 2 mi further away from the lake and a single barrier near the Bishop-Ford Expressway crossing will be able to block two pathways: Calumet River and Grand Calumet River. Both scenarios require mitigation for flood risk management to bring the increased water levels on the CAWS to the existing condition. Figure E.20 shows the comparison of the maximum water levels on the CAWS. The 500-year Lakefront Hydrologic Separation mapping revealed that for a Hydrologic Separation dam located at O'Brien Lock, because of the surrounding low-lying areas, the dam tiebacks would extend for miles on both overbanks through densely populated urban areas. It seemed an obvious choice to relocate the dam at the Bishop Ford Expressway where high ground tiebacks were already in place and required only a dam a few hundred feet wide in the channel. This also eliminated the need for a dam on the Grand Calumet River and the mitigation requirements associated with an additional separation structure. Therefore, although the water level on the CAWS is higher with Scenario E1, the Bishop-Ford Expressway crossing area is a better location than the O'Brien Lock and Dam.

E.8.1.3 Operation of CRCW and Chicago Lock (Scenario A3 versus D3)

The hydrologic separation locations on the CAWS for Scenarios A3 and D3 are identical. The difference between these scenarios is that the sluice gates and Lock at CRCW remain open all the time for Scenario A3, whereas the gates at CRCW will begin to open when the water level on the CAWS near CRCW rises from −2 ft CCD (577.20 ft NAVD) to 0.8 ft CCD (580.00 ft NAVD) for Scenario D3.

Figure E.21 shows the maximum water levels for these two scenarios. The results do not show noticeable difference, and thus, the decision on whether to operate the existing lakefront structures while the physical barrier is placed on the CSSC near the Stickney WRP outfall may be based on considerations other than flood risk management. However, note that pumping stations at the lakefront will be needed to maintain the CAWS at the currently regulated levels.

E.8.1.4 Removal of CRCW and Chicago Lock (Scenario A3 versus C3)

The hydrologic separation locations on the CAWS for Scenarios A3 and D3 are identical. The difference between these scenarios is that the sluice gates and lock at the CRCW remain open all the time for Scenario A3, whereas the dam including the sluice gates and lock at CRCW are removed for Scenario C3. Figure E.21 shows the maximum water levels for these two scenarios. The maximum water level for the scenario in which the CRCW structure is removed is slightly lower because of an increased conveyance of Chicago River water without the obstruction of dam structure

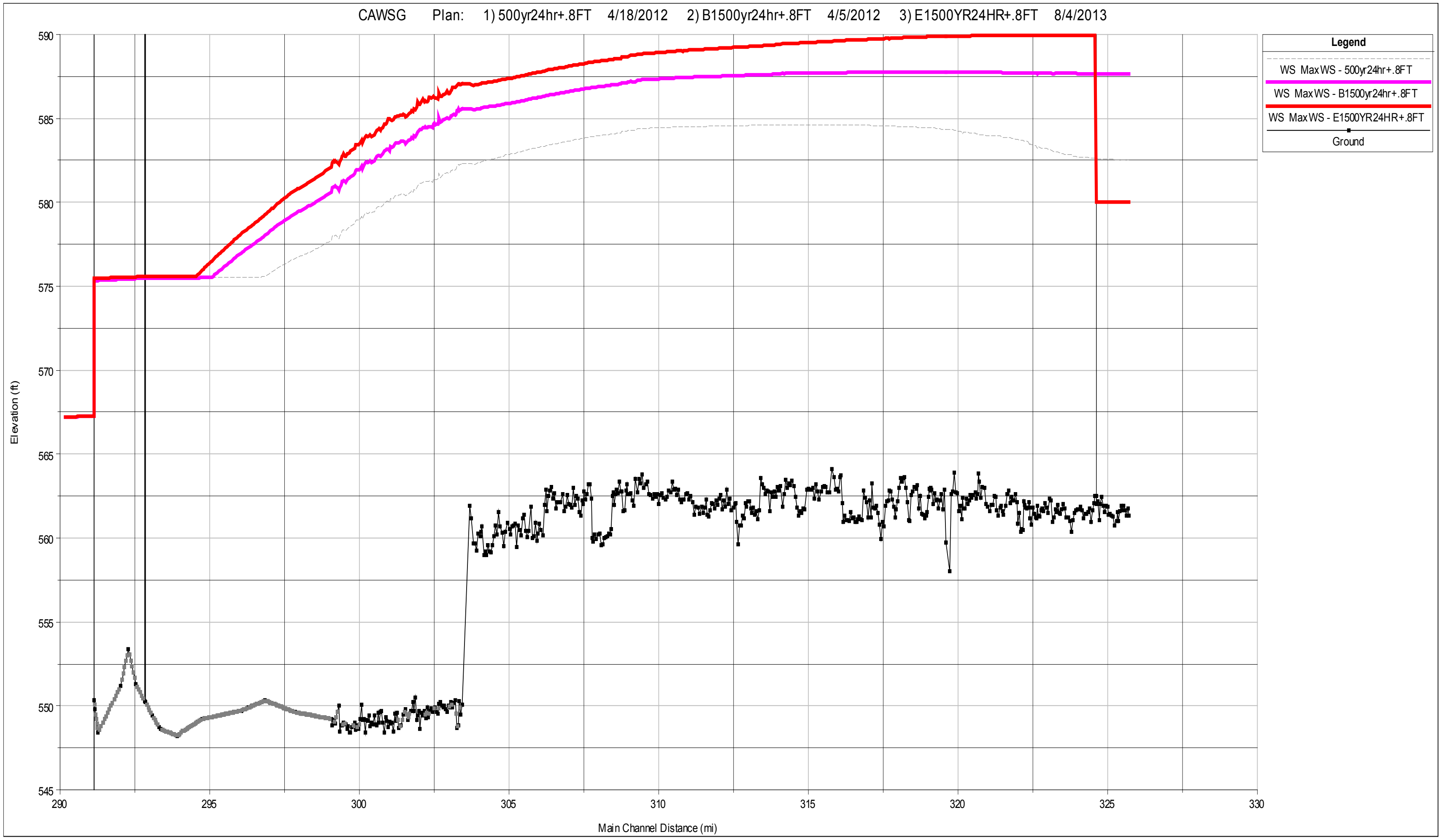

FIGURE E.20 Comparison of 500-Year Maximum Water Surface Elevation on the CSSC, Cal-Sag Channel, and North Little Calumet River for the Future Condition (Location near O'Brien Lock and Dam)

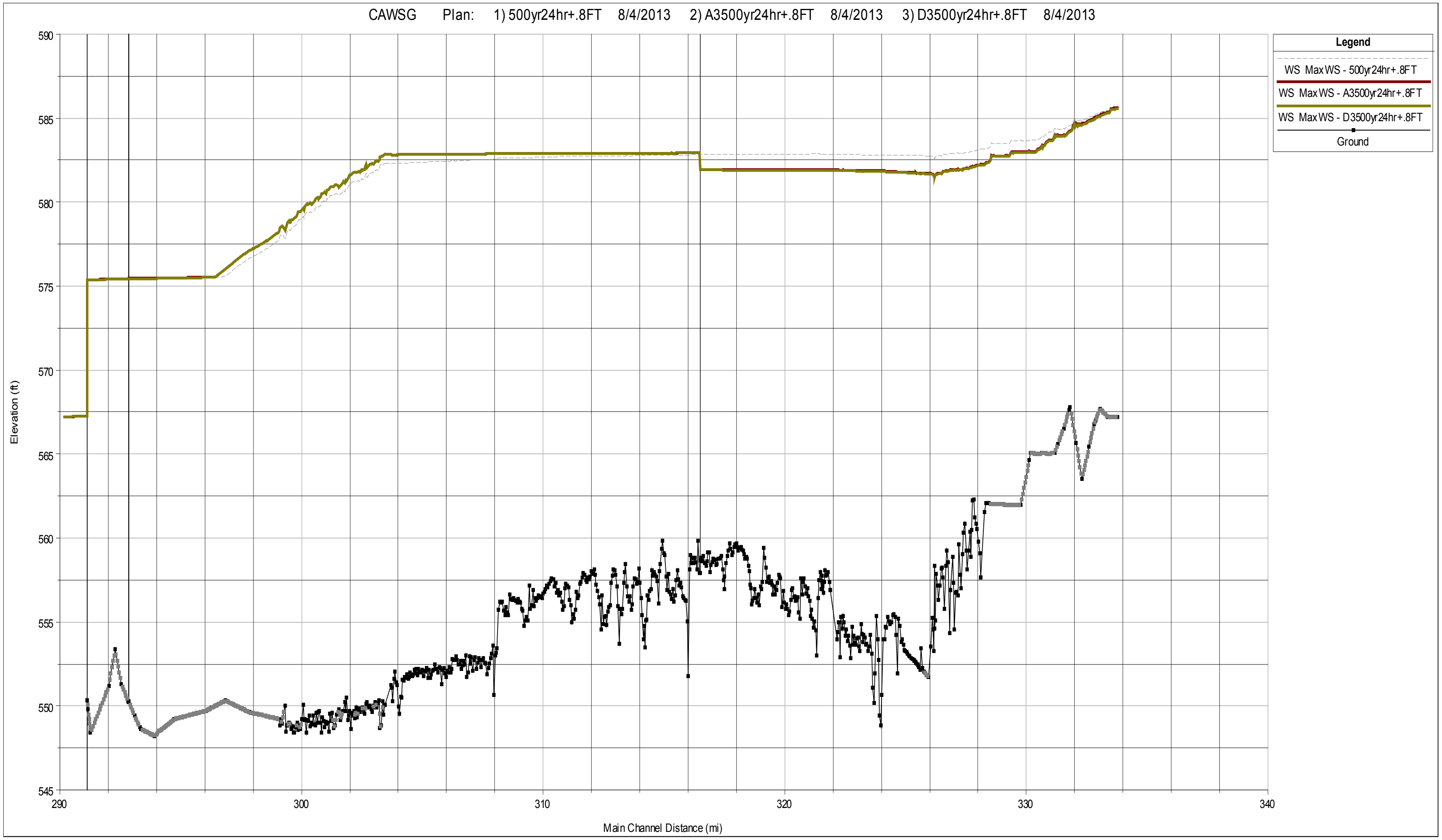

FIGURE E.21 Comparison of 500-Year Maximum Water Levels on the CSSC, South Branch of the Chicago River, and North Branch of the Chicago River for the Future Condition (operation of CRCW and Chicago Lock)

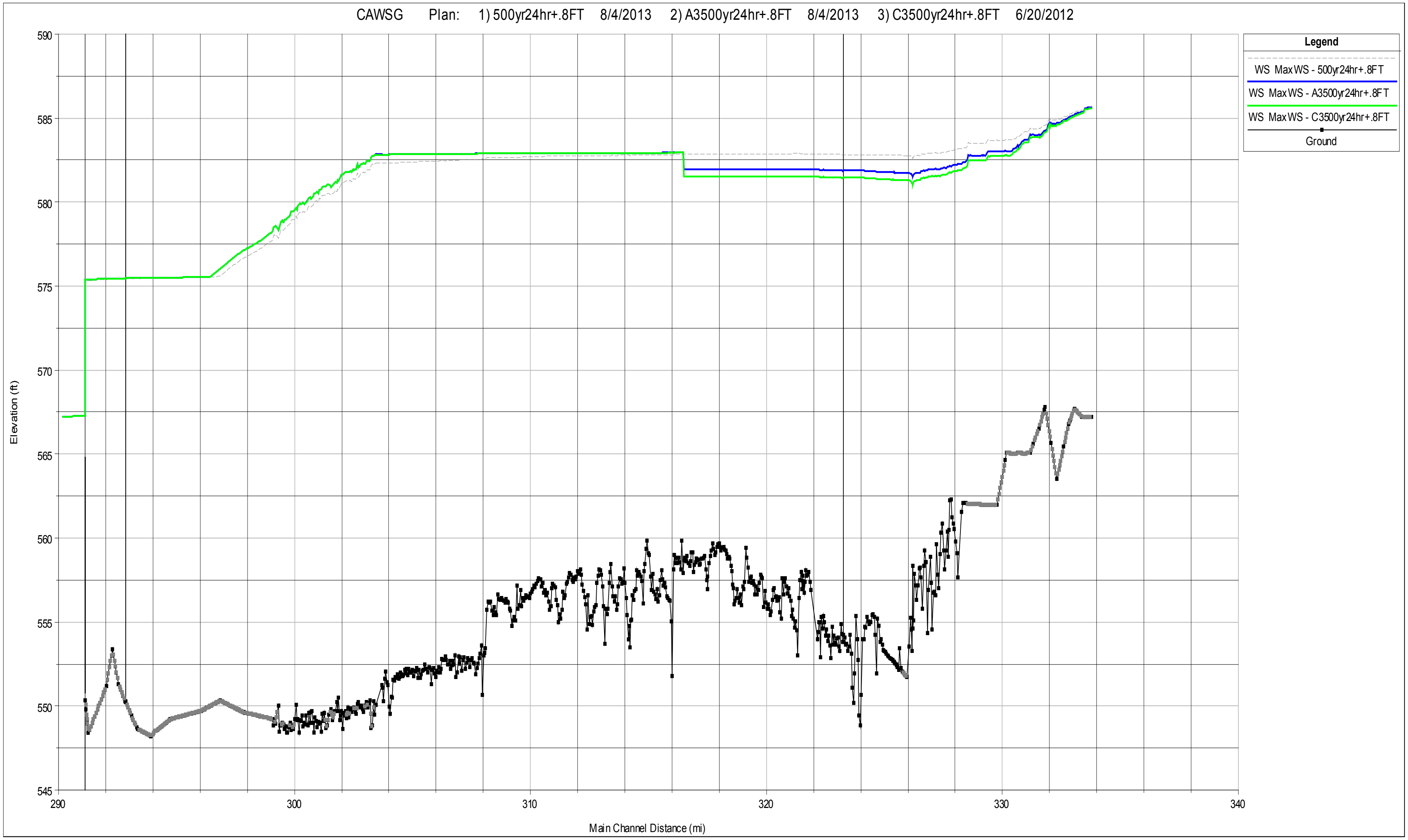

FIGURE E.22 Comparison of 500-Year Maximum Water Levels on the CSSC, South Branch of the Chicago River, and North Branch of the3 Chicago River for the Future Condition (Removal of CRCW and Chicago Lock)

E.8.2 Physical Barrier Crest Elevation

Physical barrier crest elevations were set by using the higher of the pre-project 500-year baseline flood event plus 3 ft of freeboard or a high lake level plus setup plus 3 ft of freeboard. For the Hart Ditch location the barrier was set at the elevation of the lowest nearby overflow location.

E.8.3 Food Risk Mitigation

The flood mitigation components included tunnels and reservoirs that store the volume of water that would be backflowed to Lake Michigan during a 500-year synthetic flood event. Tunnels would connect the WPS and the CRCW to the reservoir site near the McCook quarry area; also, a tunnel would direct floodwater from the O'Brien Lock to Thornton. The tunnels were sized such that they could convey the peak backflow as computed by the HEC-RAS model. The Darcy-Weisbach equation was used to compute the head loss. The design of inlet structures along the streambank of the waterway is beyond the current scope of work. It is assumed that the existing Mainstream and Calumet Pumping Station can pump water out from these reservoirs to the Stickney and Calumet WRP for processing, respectively, after the plant completes dewatering of the TARP tunnels and reservoirs.

E.8.3.1 Tunnels

In the process of sizing the Hydrologic Separation flood risk management mitigation tunnels, the 500-year synthetic event peak flows were assumed. The tunnels for the Lakefront Hydrologic Separation Alternative were sized based on the future hydrologic condition assuming that the construction of the mitigation tunnels and reservoirs would not be complete before 2029. The 500-year baseline condition peak flood flows were used to size the Mid-System Hydrologic Separation reservoirs. It was assumed that the smaller mitigation tunnels and reservoirs required for the Mid-System Separation Alternative could possibly be in place during the baseline hydrologic condition prior to the 2029 future condition.

To size the tunnels, the available head loss estimate included accounting for the flood volume in the reservoirs prior to the arrival of the peak flow through the tunnel. An area for the footprint of the proposed reservoir was assumed; it was also assumed that the bottom elevation of the proposed mitigation reservoir would be the same as that of the existing reservoirs where applicable. The flood volume prior to peak was then used to estimate a stage in the reservoir at the time of the peak flow. The difference in head loss between the stage at the upstream tunnel inlets and the stage downstream in the reservoir was then used to size the tunnels.

A spreadsheet was used for preliminary sizing. HEC-RAS models were developed for the final sizing. Some allowance was made for other losses, but no design of inlets or outlets was performed. Much more detailed modeling and design considerations would be required for the actual design of these tunnels should they be selected to move forward to construction.

E.8.3.2 Reservoirs

As noted above for the sizing of the Hydrologic Separation tunnels, the 500-year synthetic event flows (total flow volumes) were used to size the Hydrologic Separation flood risk management mitigation reservoirs. The reservoirs for the Lakefront Hydrologic Separation were sized based on the future condition assuming that the construction of the mitigation tunnels and reservoirs would not be complete before 2029. The 500-year baseline condition flood flows were used to size the Mid-System Hydrologic Separation reservoirs. It was assumed that the smaller mitigation tunnels and reservoirs required for the Mid-System Separation alternative could possibly be in place prior to the 2029 future condition.

E.8.4 Lakefront Hydrologic Separation

The Lakefront Hydrologic Separation Alternative has the lowest adverse impact on the water quality in Lake Michigan. However, it imposes a significant risk of overbank or basement flooding, which requires (flood risk) mitigation.

E.8.4.1 Maximum Water Levels on CAWS

The computed maximum water surface elevations on the CAWS for the eight modeled frequencies are provided in Figures 19 through 26 in Enclosure B. The comparison of the maximum water surface elevations on the CAWS for the 100-year event between the no-project and with-project conditions are provided in Figures 35 through 42 in Enclosure B.

E.8.4.2 Physical Barriers Crest Elevation

The Lakefront Hydrologic Separation Alternative includes four barrier locations (in HEC-RAS model).

Wilmette Pumping Station on the North Shore Channel at River Mile 340.795/1008.

Crest elevation of barrier based on river level = 500-year baseline flood level (river side) + 3 ft freeboard = 584.2 ft NAVD + 3 ft =587.2 ft NAVD

Crest elevation of barrier based on lake level = high lake level + high setup = 3.7 ft CCD + 3.0 = + 6.7 ft CCD = 585.9 ft NAVD

Elevation of the top of the proposed barrier = higher of river or lake = 587.2 ft NAVD

Chicago River Controlling Works on the Chicago River at River Mile 327.12/1033.

Crest elevation of barrier based on river level =500-year baseline flood level (river side) + 3 ft freeboard = 582.7 ft NAVD + 3 ft =585.7 ft NAVD

Crest elevation of barrier based on lake level = high lake level + high setup = 3.7 ft CCD + 3.0 = +6.7 ft CCD = 585.9 ft NAVD

Elevation of the top of the proposed barrier = higher of river or lake = 585.9 ft NAVD

Upstream of O'Brien Lock on the Little Calumet River North at River Mile 324.50 (near Bishop-Ford Expressway Crossing).

Crest elevation of barrier based on river level = 500-year baseline flood level (river side) + 3 ft freeboard = 582.7 ft NAVD + 3 ft =585.7 ft NAVD

Crest elevation of barrier based on lake level = high lake level + high setup = 3.7 ft CCD + 3.0 = + 6.7 ft CCD = 585.9 ft NAVD

Elevation of the top of the proposed barrier = higher of river or lake = 585.9 ft NAVD

Little Calumet River South at River Station 86446 (approximately 1000 ft west of Hart Ditch). The Hart Ditch physical separation barrier is located in the middle of an existing USACE flood control levee project. Additional considerations were taken into account for this location based on the existing USACE levee system functionality. Crest set at 603.4 ft NAVD (set at the lowest overflow elevation near Hart Ditch).

E.8.4.3 Flood Mitigation Components

Flood mitigation components include tunnels and reservoirs.

Mitigation Tunnels. Tunnel alignments assumed for conveying flows from the lakefront barrier structures to the McCook hydrologic separation mitigation reservoir were assumed to start at the WPS separation structure and then to the CRCW separation structure; then another tunnel from the CRCW separation structure to the proposed McCook mitigation reservoir site.

Two tunnel alignments were assumed for the mitigation tunnel for the Thornton Reservoir site. One alignment begins near the Little Calumet River confluence with the Cal-Sag Channel and then proceeds to the proposed Thornton mitigation reservoir site. A separate tunnel begins at the Lakefront Hydrologic Separation structure on the Little Calumet River just west of Hart Ditch and ends at the proposed Thornton Reservoir site.

Mitigation Reservoirs. Three reservoirs are included with the Lakefront Hydrologic Separation Alternative. One reservoir is assumed to be located at the McCook Reservoir site, and two others are assumed to be located at the Thornton Reservoir site.

In the process of sizing the Lakefront Hydrologic Separation reservoirs, it was assumed that the backflow volumes that would normally go to the lake through the locks and sluice gates of the lakefront controlling works during the existing operating conditions would instead go into tunnels to the mitigation reservoirs, so the total backflow volumes were used to size the reservoirs, thus maintaining the flow regime in the CAWS, to mitigate for any increase in flood stages that would result from the Lakefront Hydrologic Separation.

In addition to the lakefront structures, an additional hydrologic separation point was required in the Little Calumet River basin to prevent the spread of ANS through that hydrologic pathway to the maximum extent possible as well. There is a flow split during flood conditions where flow divides and flows both to the east and to the west along the Little Calumet River from its confluence with Hart Ditch.

Effect of CUP Reservoir Occupancy. Based on a period-of-record (1949–2000) simulation the chance that the CUP McCook reservoir is not empty (>0% filled) at onset of a rain event is 37%, and the chance that the reservoir is more than 32% filled is 4%. The effect and risk of the non-empty CUP reservoirs prior to the 500-year design storm so that a larger flood risk management mitigation reservoir may be required is considered in the cost analysis.

E.8.5 Mid-System Hydrologic Separation

The Mid-System Hydrologic Separation Alternative has the least adverse impact on overbank or basement flooding. However, it imposes a risk of water quality degradation in Lake Michigan that requires (water quality) mitigation.

E.8.5.1 Maximum Water Levels on CAWS

The computed maximum water surface elevations on the CAWS for the eight modeled frequencies are provided in Figures 27 through 34 in Enclosure B. The comparison of the maximum water surface elevations on the CAWS for the 100-year event between the no-project and with-project conditions are provided in Figures 35 through 42 in Enclosure B.

E.8.5.2 Physical Barrier Crest Elevation

The Mid-System Hydrologic Separation Alternative includes three barrier locations (in HEC-RAS model).

CSSC at River Mile 316.01 (East of Stickney WRP outfall, RS 315.81).

Crest elevation of barrier based on river level = 500-year baseline flood level (river side) + 3 ft freeboard = 584.2 ft NAVD + 3 ft =587.2 ft NAVD

Crest elevation of barrier based on lake level = high lake level + high setup = 3.7 ft CCD + 3.0 = + 6.7 ft CCD = 585.9 ft NAVD

Elevation of the top of the proposed barrier = higher of river or lake = 587.2 ft NAVD

Cal-Sag Channel at River Mile 315.89 (West of Natalie Creek confluence, RS 315.91)

Crest elevation of barrier based on river level = 500-year baseline flood level (river side) + 3 ft freeboard = 585.1 ft NAVD + 3 ft =588.1 ft NAVD

Crest elevation of barrier based on lake level = high lake level + high setup = 3.7 ft CCD + 3.0 = + 6.7 ft CCD = 585.9 ft NAVD

Elevation of the top of the proposed barrier = higher of river or lake = 588.1 ft NAVD

Little Calumet River South at River Station 86446 (Approximately1,000 ft west of Hart Ditch)

Crest set at 603.4 ft NAVD (set at the lowest overflow elevation near Hart Ditch)

E.8.5.3 Flood Mitigation Components

Flood mitigation components include tunnels and reservoirs.

Mitigation Tunnels. The tunnel alignment assumed for the Mid-System Hydrologic separation barrier on the CSSC begins lakeward (east) of the barrier and conveys flood flows to the McCook hydrologic separation mitigation reservoir. The mid-system hydrologic separation barrier on the Cal-Sag Channel did not cause adverse stage impacts and thus did not require a mitigation tunnel; however, Stony Creek provides a potential hydrologic pathway for ANS transfer through the storm sewer on Cicero Avenue near 111th Street.

A minor physical barrier will be constructed in the storm sewer. A small culvert will convey flow to the nearby reservoir close to the barrier to mitigate stage impacts on Stony Creek. Because of the minor nature of the cost of this culvert in comparison to the overall costs of mitigation, the details of this connection will be studied in more detail if the study is carried forward to the next phase.

The Hart Ditch Separation Structure is also required for the Mid-System Hydrologic Separation Alternative. As noted above, this tunnel begins at the hydrologic separation structure on the Little Calumet River just west of Hart Ditch and ends at the proposed Thornton mitigation reservoir site.

E.8.5.3.1 Mitigation Reservoirs

Three reservoirs were required for flood risk management stage mitigation for the Mid-System Hydrologic Separation Alternative. For the CAWS, only a reservoir for the Mid-System Hydrologic Separation barrier on the CSSC was required. No adverse stage impacts were caused by the barrier on the Cal-Sag Channel. A mitigation reservoir near 111th Street and Cicero in Oak Lawn, Illinois, is required for the Stony Creek separation barrier, mentioned above. The Mid-System Hydrologic Separation Alternative also requires a barrier located on the Little Calumet River just west of Hart Ditch, along with its associated stage mitigation tunnel and reservoir components.

Although many of the stage impacts were confined to the CAWS channels and in many cases not a problem for Illinois Department of Natural Resources, Office of Water Resources (IDNR-OWR), construction in a floodway permit requirements, stage impacts were mitigated to prevent any induced basement flooding damages that may be caused by the barrier. The reservoir for stage mitigation on the CAWS reaches the CSSC, the North and South Branches of the Chicago River, and the NSC, was sized using the HEC-RAS model by trying various overflow weir sizes and elevations to mitigate for all stage impacts for all the various synthetic flood events. The weir (inlet for tunnel to McCook Mid-System Hydrologic Separation Mitigation Reservoir) in the model was located approximately 1 mi lake ward (east) of the barrier on the CSSC. The 500-year flow volume over the weir was then used to size the reservoir.

Effect of CUP Reservoir Occupancy. With the Mid-System Hydrologic Separation Alternative, additional reservoirs are required to capture combined sewers for water quality mitigation purposes. Therefore, the CUP reservoir occupancy does not increase costs or reduce the frequency of event that the project alternative would protect against. However, it would affect the efficiency of water quality mitigation.

E.8.5.4 Effect of Lake Level

The maximum water surface elevation in the CAWS on the lake side of the Mid-System Hydrologic Separation barriers will be affected by the lake level. The long-term mean water level (580 ft NAVD) was assumed in modeling. To quantify the effect of lake level, a sensitivity analysis was performed, and the results are provided in Figures E.24 and E.25.

E.8.6 Flow Bypass Alternative

Although not included in the Mid-System Hydrologic Separation Alternative, an additional hydrologic separation is required for the Mid-System Control Technologies without a Buffer Zone (Flow Bypass)

Alternative. This alternative maintains the O'Brien Lock location for navigation. Maintaining the O'Brien location requires a physical separation barrier on the Grand Calumet River to cut off that hydrologic pathway from ANS transfer. The location selected for the barrier is at the Illinois-Indiana state line.

E.8.6.1 Mitigation Reservoir

With the barrier on Grand Calumet River in place, a reservoir was required to mitigate for stage impacts due to the construction of the barrier. This stage mitigation targeted all the synthetic events with impacts, to ensure that any induced stage increases did not translate into induced basement flooding damages. Similar to the mid-system reservoir on the CAWS, this reservoir was sized by finding a lateral weir length and crest elevation that would pass flow necessary to mitigate for all the stage impacts.

E.8.7 CAWS Buffer Zone Alternative

Screens are required at the sluice gates at the WPS, the CRCW, and O'Brien Lock and Dam to allow backflow during significant hydrologic events. Additional sluice gates with screens will also be added to compensate for the loss of flow conveyance through the lock chamber as well as the increased head loss due to the screens.

The net spacing between bars in the screen was determined by the natural resources team (not really an assumption). The spacing of 0.4 in. (not 4 in.) will block the ANS of concerns. The head difference between the lake and river for the design condition is 3 ft. Kirschmer's equation was used to compute the head loss across the screen:

$$h_s = K_s \left(\frac{t}{b}\right)^{\frac{4}{3}} \frac{v^2}{2g} \sin\alpha$$

Based on the design of the current screens installed in the sluice gates at the CRCW and the O'Brien Lock and Dam with concurrence by the structural engineering team, the same bar width of 3/8 in. was used in computation. In the conceptual design the bar will have a circular cross section, and the screen will be installed vertically. No blockage of screen open space due to debris was assumed. The computed head loss due to the bar screen was 0.57 ft. The existing gate is 10 ft by 10 ft, and the recommended new gate will be 10 ft wife by 15 ft high to allow more flow through the same width of the dam structure. Additional information is provided in Appendix I.

Currently, the 2-in. bar screens have been installed at some sluice gates at the CRCW and the O'Brien Lock and Dam to reduce the risk of Asian carp transfer from the rivers to Lake Michigan. No major debris issues have been reported. However, a proper raking system will be included to keep debris away from the gate and finer screen structures.

E.8.8 Hybrid Cal-Sag Open Alternative

An additional hydrologic separation is also required for the Mid-System Separation Cal-Sag Open Control Technologies with a Buffer Zone (the Hybrid Cal-Sag Open) Alternative. This alternative maintains the O'Brien Lock location for navigation. Maintaining the O'Brien location requires a physical separation barrier on the Grand Calumet River to cut off that hydrologic pathway from ANS transfer. The location selected for the barrier is at the Illinois-Indiana state line. The required mitigation reservoir is discussed in Section E.8.6.1.

Screens are required at the sluice gates at the O'Brien Lock and Dam to allow backflow during significant hydrologic events. Additional sluice gates with screens will be installed to compensate the loss of flow conveyance through the lock chamber. The bar screen was assumed to have a clear spacing of 3/8 in. The peak flows at the O'Brien Lock and Dam for the no-project condition were used to determine the number of sluice gates and the size of the gate opening.

E.8.9 Hybrid CSSC Open Alternative

Screens are required at the sluice gates at the WPS and the CRCW to allow backflow during significant hydrologic events. The bar screen was assumed to have a clear spacing of 3/8 in. Additional sluice gates with screens will be installed to compensate the loss of flow conveyance through the lock chamber. The peak flows at the WPS or the CRCW for the no-project condition were used to determine the number of sluice gates and the size of the gate opening.

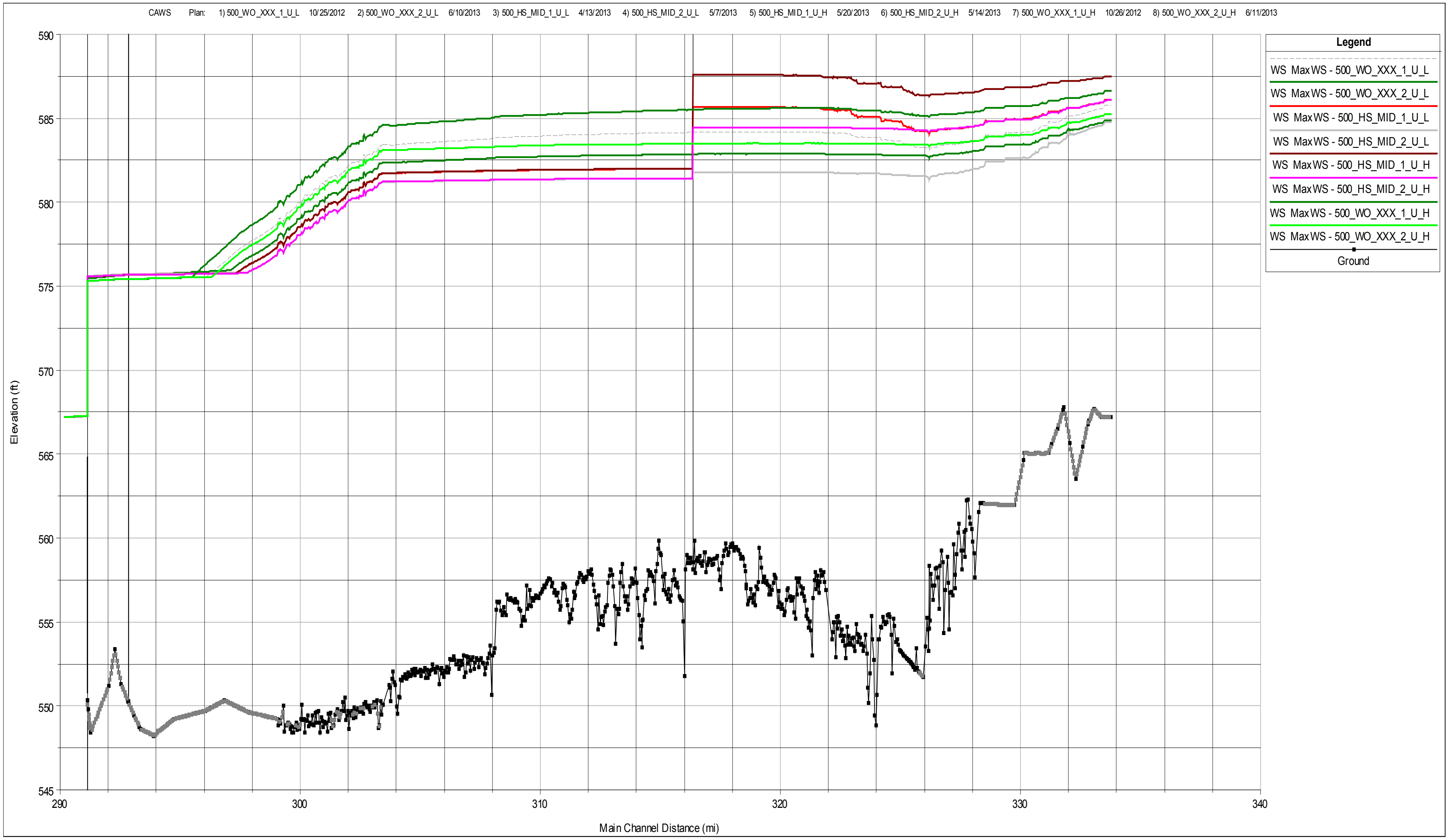

FIGURE E.23 Comparison of 500-Year Maximum Water Levels on the CSSC, South Branch of the Chicago River, and North Branch of the Chicago River for the Future Condition (Lake = L = 580), Future with Mid-System Hydrologic Separation (Lake = L = 580), Future Condition (Lake = H = 583), and Future with Mid-System Hydrologic Separation (Lake = H = 583)

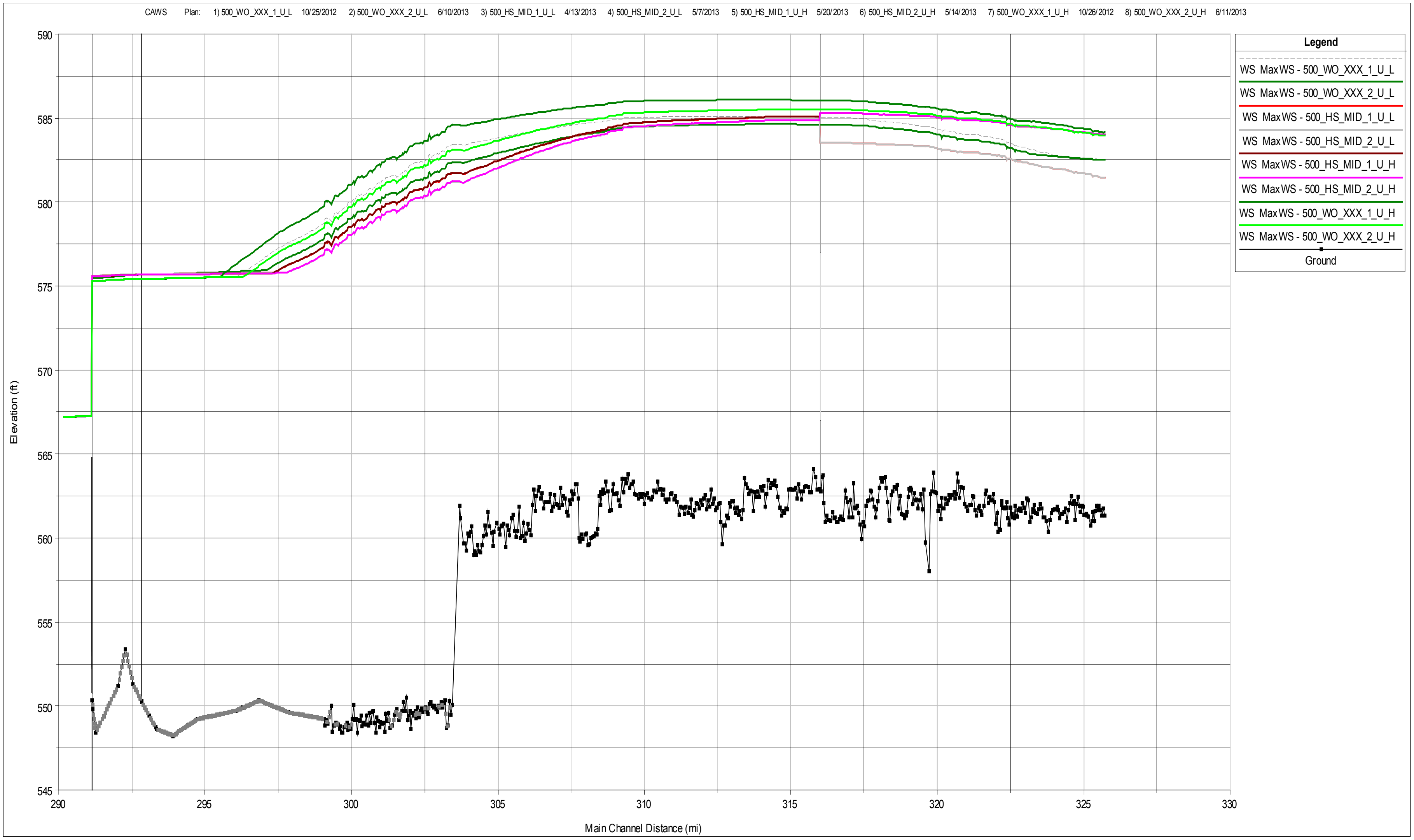

FIGURE E.24 Comparison of 500-Yyear Maximum Water Levels on the CSSC, Cal-Sag Channel, and North Little Calumet River for the Future Condition (Lake = L = 580), Future with Mid-System Hydrologic Separation (Lake = L = 580), Future Condition (Lake = H = 583), and Future with Mid-System Hydrologic Separation (Lake = H = 583)

E.9 IMPACT ON LAKE MICHIGAN DIVERSION

Since most alternatives tend to decrease diversion, the State of Illinois can continue managing the allowed lake water diversion without triggering disputes among the Great Lakes states. As long as the diversion under the with-project condition is within the currently mandated limit, the change in diversion for GLMRIS is not considered either positive or negative. Therefore, diversion is a neutral factor in evaluation of alternatives.

The analyses presented in this report were based on a simplified inflow-to-CAWS approach that could reasonably evaluate the effect of the hydrologic separation on diversion in quantitative terms. However, the mandated diversion accounting procedures and much more complicated modeling processes must be followed to refine the results for any future technical or legal discussions.

E.9.1 Lake Michigan Diversion

Currently, the State of Illinois is allowed to divert 3,200 cfs from Lake Michigan and the Lake Michigan watershed that used to drain to Lake Michigan before three man-made canals were completed between 1900 and mid-1922. In addition, storm runoff lake water can be diverted for domestic water supply, maintaining the waterway in a reasonably sanitary condition, and facilitating navigation. The latest legal mandate for Lake Michigan diversion is documented in the U.S. Supreme Court Decree in the *Wisconsin, et al. v. Illinois et al.*, 388 U.S. 426, 87 S.Ct. 1774 (1967) as modified by 449 U.S. 48, 101 S. CT. 557 (1980), and the Interstate Compact on the management of Great Lakes water resources adopted the U.S. Supreme Court decree regarding the interbasin diversion at Chicago.

E.9.2 Impact on Diversion

To evaluate the impacts of GLMRIS on Lake Michigan water diversion, it is important to know the components of diversion. Basically, the diversion consists of three major components: (1) basin runoff, (2) domestic water supply in the form of effluent from the wastewater treatment plants or untreated combined sewer overflow, and (3) direct diversion from the lakefront controlling structures. Within the CAWS there are three lakefront controlling works that regulate the amount of water exchanged between the waterway and Lake Michigan. These facilities are located on the NSC in Wilmette, on the Chicago River in downtown Chicago, and on the Calumet River about 7 mi from the lake shore and are known as the WPS, the CRCW, and the O'Brien Lock and Dam, respectively. Lake water is diverted from these structures for discretionary use (i.e., dilute the pollutants in the waterway) or because of uncontrollable leakage. At the CRCW and the O'Brien Lock and Dam, diversion also occurs as a result of lockage and navigation makeup. Lockage moves the commercial cargo, commercial non-cargo, and recreational vessels between the waterway and Lake Michigan, whereas the navigation makeup is needed to maintain the water depth at the CRCW and the O'Brien Lock and Dam as required by CFR. During significant storm events, backflow through these structures may also occur. Backflow is considered negative diversion, and thus any modifications to the backflow by the GLMRIS alternatives will affect diversion. Table E.14 shows the major components of Lake Michigan diversion that will be affected by the GLMRIS alternatives.

The red squares in Figure E.25 represent the locations of the Stickney, Calumet, and Lemont WRPs owned and operated by the MWRDGC. Without rerouting. the effluent discharge from the Calumet WRP will go into Lake Michigan, whereas the discharges from the Stickney and Lemont WRPs will continue flowing to Lockport. The effluent discharge from the WRPs consists of the return flow from water supply use during dry weather and from mixes of water supply and stormwater during wet weather. With the Mid-System Hydrologic Separation Alternative, the flow that will return to Lake

TABLE E.14 Impact Matrix for Lake Michigan Diversion

Alternative	Runoff	Water Supply	Direct Diversion: Lockage	Direct Diversion: Leakage	Direct Diversion: Discretionary	Direct Diversion: Navigation Makeup	Back Flow
Lakefront Hydrologic Separation							X
Mid-System Hydrologic Separation	X	X		X			X

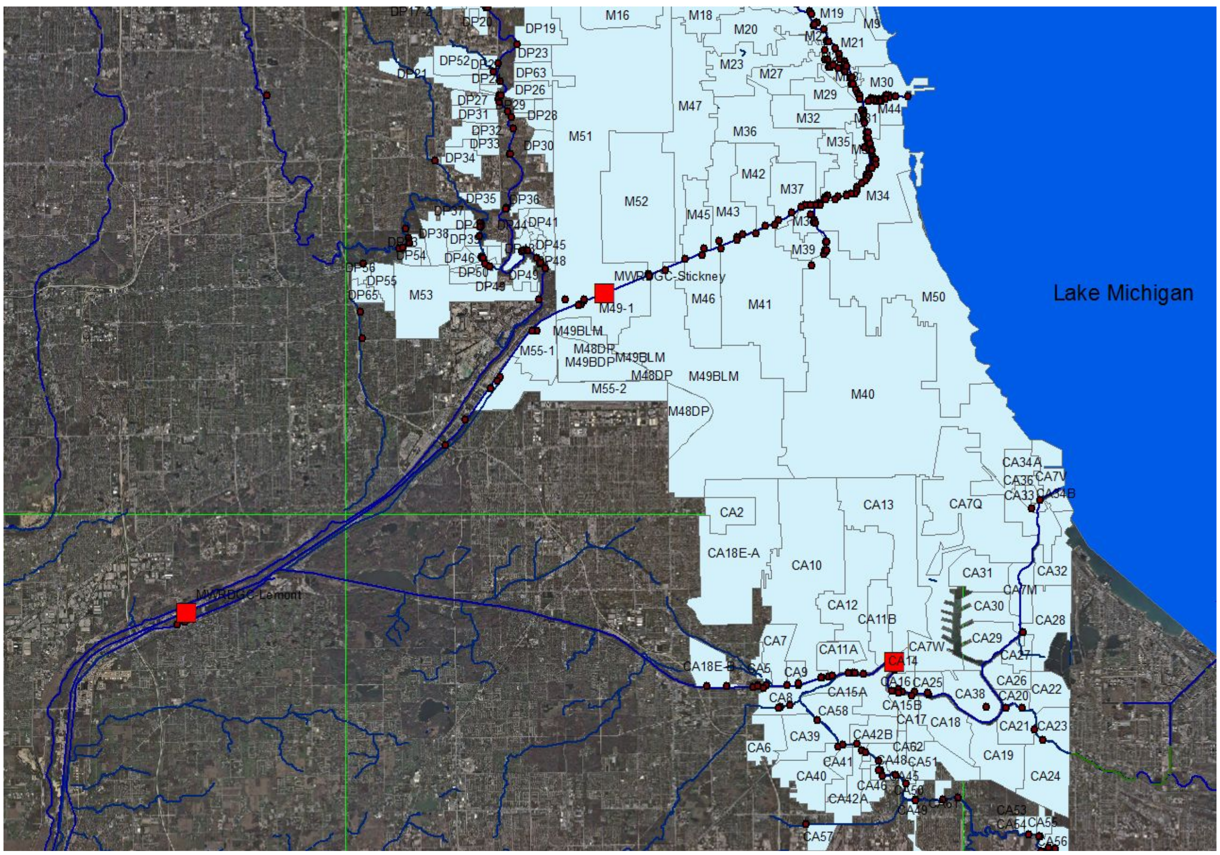

FIGURE E.25 CSO Outfalls and MWRDGC WRPs

Michigan instead of to Lockport includes the WRP effluents from the O'Brien and Calumet WRPs and most CSOs except a few located on the river side of the barrier on the CSSC, as shown in Figure E.20. In addition, only a handful among the few connected to the Special Contributing Areas (SCAs) are in the Lake Michigan watershed. These CSO outfalls drain SCAs M48, M49, M49-1, M51, M55-1, and M55-2.

The last segment of the TARP tunnel network, that is, the Little Calumet River leg, was completed in 2006. The tunnel network after 2006 represents the current sewer drainage system in the CAWS basin. In addition, the last diversion accounting report was published for WY 2009. The certified annual mean diversion flows are 3,094 cfs, 3,002 cfs, and 3,135 cfs, for WY 2007, WY 2008 and WY 2009, respectively. Although diversion varies from year to year, the intent of the analysis is to provide a quantitative measure of the effect of different alternatives on the diversion flow in relative terms. For illustrative purposes, therefore, WY 2008 was chosen in the impact analysis.

To assess the impact of GLMIRIS alternatives on Lake Michigan diversion, the following assumptions were made:

- Any flows from the Des Plaines River watershed that drains to Lake Michigan will be considered as negative diversion, that is, diversion into the Lake Michigan basin.

- Lockage, navigation makeup, or discretionary diversion will not be changed to maintain the current navigation function and water quality on the CAWS.

E.9.2.1 No New Federal Action Alternative

With the No New Federal Action Alternative, the discretionary diversion is the only component of diversion that may be subject to change in the future after the completion of the TARP reservoirs. The IDNR makes allocation of the allowed Lake Michigan diversion. Currently, the allocation for discretionary use is 270 cfs, but the allocation will be reduced to 101 cfs beginning WY 2105 upon completion of the Thornton and McCook CUP reservoirs based on past analysis. However, the construction of CUP reservoirs has been delayed, and the McCook stage-2 reservoir is currently scheduled to come on-line in 2029. Thus, MWRDGC, the agency that needs the discretionary water to maintain the canal system in a reasonably sanitary condition, is contemplating submitting a petition for extension of the current allocation level. The IDNR will review the application and supporting documents (new study results) to determine the proper discretionary allocation in the future. However, the No New Federal Action Alternative will not affect the decision.

E.9.2.2 Lakefront Hydrologic Separation Alternative

The diversion will be slightly changed because the runoff in the Grand Calumet River from the state of Indiana and the CSOs from a few outfalls on the lake side of the barriers will flow to Lake Michigan.

With the Lakefront Hydrologic Separation Alternative, the flood mitigation reservoirs will be built to store the backflow that is currently allowed to discharge to Lake Michigan during significant storm events. The diversion will also be affected by eliminating the backflow during such rare events.

In WY 2008 the flows were −4 cfs, −3 cfs, and 47 cfs for the Grand Calumet River runoff, the CSO between the barriers and the existing lakefront control structures, and backflow to Lake Michigan, respectively. The certified diversion for WY 2008 was 3,002 cfs. The estimated diversion with the Lakefront Hydrologic Separation Alternative will be increased by 40 cfs, 1.3% of the diversion for WY 2008.

E.9.2.3 Mid-System Hydrologic Separation Alternative

The Mid-System Hydrologic Separation Alternative has a significant impact on diversion. The discussion for each flow component is more detailed in this section here than in the general categories outlined in Table E.13.

Impact Evaluation.

Effluent from O'Brien WRP. In WY 2008 the average discharge from the O'Brien WRP was 362 cfs, which consists of 353 cfs from the Lake Michigan watershed, 14.5 cfs from the Des Plaines watershed, and 5.3 cfs for plant recycle. This flow will reach Lake Michigan with the Mid-System Hydrologic Separation Alternative, and the diversion will be reduced by 353 cfs.

Effluent from Calumet WRP. In WY 2008 the average discharge from the Calumet WRP included 333 cfs pumped from the interceptors and 88 cfs pumped from the TARP. This flow will reach Lake Michigan with the Mid-System Hydrologic Separation Alternative, of which 86% of the total (, i.e., 362 cfs) is from the Lake Michigan watershed.

Effluent from Stickney WRP. In WY 2008 the average discharge from the Stickney WRP included 976 cfs pumped from the interceptors and 161 cfs pumped from the TARP. The diversion will not be changed because the Stickney outfall is on the river side of the barrier.

CSO to Chicago River System. In WY 2008 the total CSO adjacent to the mainstream TARP system and discharged to various reaches of the Chicago River waterway system was 164 cfs, 161.2 cfs from the Lake Michigan watershed and 2.8 cfs from the Des Plaines watershed. The CSO from SCAs M48, M49, M49-1, M51, M55-1, and M55-2 continued to flow to Lockport. The total CSO from the above SCAs was about 36 cfs. Therefore, the diversion will be reduced by 128 cfs. With the Mid-System Hydrologic Separation Alternative, a portion of CSOs will be captured by the McCook Reservoir during large storm events. The water in the reservoir will be treated by the Stickney WRP before being discharged to the river side of the barrier on the CSSC. This means a portion of CSO that is currently discharged to multiple locations at the lake side of the barrier on the CSSC will discharge, after treatment, to the river side at the Stickney WRP outfall. For the future condition the diversion will be reduced from 128 cfs to 40 cfs.

CSO to Calumet River System. In WY 2008 the total CSO adjacent to the Calumet TARP system and discharged to various reaches of the Calumet River system was 87 cfs, all of which is from the Lake Michigan watershed, including 7.3 cfs discharging to the lake side of the O'Brien Lock. Therefore, diversion will be reduced by about 80 cfs. Because the CSOs in the Calumet River system and Calumet WRP are on the lake side of the physical barrier with the Mid-System Hydrologic Separation Alternative, the reduction in diversion will not be changed by converting portions of CSOs to WRP plant discharge with the Thornton Reservoir.

Runoff from Ungaged Lower Des Plaines Basin. In WY 2008 the total runoff from the ungaged lower Des Plaines River basin was 95 cfs, all of which enters the CSSC on the river side of the barrier. This flow component will not be changed with the Mid-System Hydrologic Separation Alternative.

Runoff from Ungaged Calumet Basin. In WY 2008 the total runoff from the ungaged Calumet basin was 166 + 23 (Midlothian) + 17 (Tinley) = 206 cfs, of which about half went to the river side of the barrier and the other half to the lake side of the barrier. Therefore, the diversion will be reduced by about 103 cfs with the Mid-System Hydrologic Separation Alternative.

Grand Calumet River. In WY 2008 the total flow crossing the Illinois- Indiana state line was about 10.2 cfs, of which the runoff component was about 4 cfs. According to the decree, the runoff portion of the total flow from the state of Indiana is considered diversion. This flow will go to Lake Michigan if a physical barrier is constructed in the Cal-Sag Channel. Therefore, the diversion will be reduced by 4 cfs with the Mid-System Hydrologic Separation Alternative.

Summit Conduit. In WY 2008 it was estimated that total flow through the Summit Conduit was about 9.5 cfs. The outfall of the Summit Conduit on the CSSC is on the river side of the barrier. This flow component will not be changed with the Mid-System Hydrologic Separation Alternative.

Back Flow. In WY 2008 the total backflow at the three lakefront controlling structures was 47 cfs. With the Mid-System Hydrologic Separation Alternative, various discharges to the waterway on the lake side of the barriers will flow to Lake Michigan. This flow component will not be changed with the Mid-system Hydrologic Separation Alternative.

Spillover from Des Plaines River to CSSC. The spillover flow exists at several locations downstream from Riverside, Illinois, where the Des Plaines River and the CSSC begin to run more or less in parallel. Riverside is several miles on the river side of the barrier on the CSSC. This flow component will not be changed with the Mid-System Hydrologic Separation Alternative.

Discretionary Diversion. In WY 2008 the total discretionary diversion at three lakefront controlling structures was 269 cfs. This diversion will be affected by the online schedule of CUP reservoirs, but will not be changed with GLMRIS to maintain the CAWS in a reasonably sanitary condition.

Lockage. In WY 2008, 33 cfs was used for lockage at the CRCW and the O'Brien Lock and Dam. This diversion will not be changed with the Mid-System Hydrologic Separation Alternative to maintain the navigation function of the CAWS.

Navigation Makeup. In WY 2008, 41 cfs was used for navigation makeup at the CRCW and the O'Brien Lock and Dam. This diversion will not be changed with the Mid-System Hydrologic Separation Alternative to maintain the navigation function of the CAWS.

Leakage. In WY 2008, 22 cfs was estimated to be the leakage at all three lakefront controlling works. This diversion will be eliminated with the Mid-System Hydrologic Separation Alternative because the new physical barriers will have negligibly small leakage.

The certified diversion for WY 2008 was 3,002 cfs. The estimated diversion with the Mid-System Hydrologic Separation Alternative will be reduced by 964 cfs, 32% of the diversion for WY 2008.

Effect of Water Quality Mitigation. Water quality mitigation includes rerouting of the O'Brien and Calumet WRP discharges to the river side of the physical barriers, and capture of the remaining CSOs in the sewer system before they reach the CAWS. With these mitigation measures, a total of 835 cfs (by summing components 1, 2, 4, and 5 in Table E.15) will be zero, and the diversion will be reduced by 129 cfs, 4.3% of the diversion for WY 2008.

TABLE E.15 Summary of Impact of Mid-System Hydrologic Separation on Diversion Components

	Effect on Diversion (cfs) Future Condition	
Flow Components	Without Water Quality Mitigation	With Water Quality Mitigation
O’Brien WRP	−353	0
Calumet WRP	−362	0
Stickney WRP	0	0
CSO to Chicago River system	−40	0
CSO to Calumet River system	−80	0
Runoff from ungaged lower Des Plaines River	0	0
Runoff from ungaged Calumet	−103	−103
Grand Calumet River	−4	−4
Summit conduit	0	0
Back flow	0	0
Spillover flow	0	0
Discretionary diversion	0	0
Lockage, navigation makeup, and leakage	−22	−22
Total	−964	−129

E.10 IMPACT ON LOW FLOW

E.10.1 Lakefront Hydrologic Separation

The storm runoff and treated and untreated sanitary flows will continue flowing to the Mississippi River via the Illinois River and the CAWS. During significant storm events, additional flow will be captured in the flood mitigation reservoirs and released to the CAWS at a later time. Unlike regular flood control reservoirs, these reservoirs will not attenuate the flood peak in the waterway, nor will they affect the total volume of floodwater. During dry weather, the flood mitigation reservoir will not take in water, and thus the low flow will not be altered.

E.10.2 Mid-System Hydrologic Separation

A large portion of storm runoff and treated and untreated sanitary flows will reverse course to Lake Michigan for both wet and dry weather conditions. Therefore, the low flow in the waterway downstream from the physical barriers will be reduced. However, the mitigation components for the water quality concern may eliminate this effect, which is further discussed in the following sections.

E.10.2.1 7Q10 Low Flow

The 7-day 10-year low flows, 7Q10, is a common discharge statistic used in water resources management and water quality regulation; it represents the minimum flow in the river that needs to be maintained or that the water quality standards will apply to. Often permitted water users are not allowed to withdraw waters from the river once the discharge falls below 7Q10. In the waterway in Northeast Illinois, 7Q10 mainly consists of effluent from the wastewater treatment plants, commercial and industrial discharges, and groundwater infiltration. Since the low flow normally occurs in the winter months in Northeast Illinois watersheds, 7Q discharge usually occurs in the winter months as well. Therefore, the change in direct diversion through the lakefront controlling works from May through October will have little effect on making estimates for the 7Q10. In addition, the groundwater infiltration into the waterway was also found to be very small in the watershed's tributary to the CAWS. Therefore, the effect of the Mid-System Hydrologic Separation on the low flow in the waterway downstream from the physical barriers can simply be viewed as a result of stopping some wastewater treatment plant and commercial and industrial discharges on the lake side of the barriers to continue flowing downstream.

The most recent analysis of the 7Q10 in the Northeast Illinois streams by the Illinois State Water Survey was in 2003. It was estimated that the 7Q10 on the CSSC above the Cal-Sag Junction was about 1,050 cfs, whereas the 7Q10 in the Cal-Sag Channel above the junction was about 259 cfs. These numbers correspond reasonably well with the recently reported effluents from MWRDGC's WRPs and other municipal wastewater treatment plants during dry weather. The 7Q10 value generally increases along the course of the river when flows are added to the river by plant discharge or tributary inflows, which in turn mainly consist of WRP discharges. However, it may also decrease as a result of non-return withdrawals. With the Mid-System Hydrologic Separation Alternative, 311 cfs (O'Brien WRP and other minor inflows) plus 259 cfs (Calumet WRP and other minor inflows) (= 570 cfs) will flow to Lake Michigan if the effluents from these plant facilities are not rerouted to the river side of the barriers. In GLMRIS the 7Q10 discharges downstream from the Cal-Sag Junction with the Mid-System Hydrologic Separation Alternative (the third column) were computed by subtracting 570 cfs from the estimated values under the existing condition (the second column) and provided in Table E.16.

TABLE E.16 7Q10 Discharges in Waterway Downstream from Physical Barriers

Location	–Existing (cfs)	With Mid-System Hydrologic Separation (cfs)	With Mid-System Hydrologic Separation with Water Quality Mitigation
CSSC above Cal-Sag Junction	1,050	739	1,018
Cal-Sag Channel	259	0	213
CSSC near Lemont	1,315	745	1,237
CSSC at Lockport	1,317	747	1,239
Des Plaines River below CSSC confluence	1,471	901	1,393
Des Plaines River at Brandon Road Dam	1,493	923	1,415
Illinois River at Dresden	2,100	1,530	2,022
Illinois River at Morris	2,115	1,545	2,037
Illinois River at Marseilles	1,990	1,420	1,912
Illinois River at Ottawa	1,985	1,415	1,907

There are several lock and dams on the Illinois River to support commercial navigation. To maintain the required navigation pool, the hydropower turbine or water control gates may not allow water to pass from the upper pool to the lower pool. A reduction of approximately 25% of 7Q10 discharge in the waterway downstream from Dresden will worsen the operation conditions during droughts for several power plants that use the water in the river for once-through cooling or making up water for the close-cycle cooling system. With the reroute of O'Brien and Calumet WRP discharges, the adverse impact will be significantly reduced; this is discussed in Section E.10.2.2.

E.10.2.2 Effect of Water Quality Mitigation

The water quality mitigation components include rerouting of O'Brien and Calumet WRP effluents to downstream of the Mid-System Hydrologic Separation points, and capture of the remaining CSOs in the sewer system, to be treated later and discharged to the downstream of the Mid-System Hydrologic Separation points. With such flow augmentation, the low flow in the CAWS downstream from the physical barriers will be affected only by some minor inflows (total 78 cfs) to the waterway on the lake side of the physical barriers from commercial and industrial users or local municipal wastewater treatment plants. The low flows along the CAWS and Illinois River down to Ottawa are given in the right column in Table E.16.

E.10.2.3 Low-Flow Mitigation

The low flow can easily be mitigated by pumping 78 cfs from the lake side of the barrier on the CSSC, through the treatment plant, and discharging it to the CSSC on the river side during the low-flow period. Additional plants, pumping stations, or tunnels, except for a few small pipes, are not required because the low-flow and flood periods do not coincide and the same facilities for water quality mitigation can be used.

E.11 BASEMENT FLOODING

Enclosure C contains the report titled, "Great Lakes and Mississippi River Interbasin Study: Hydrologic and Hydraulic Impact on Sewer Systems" provided by USACE contractor CH2MHill regarding the basement flooding impacts for without-project conditions. This report demonstrates the potential for extensive basement flooding risk as a result of the proposed, unmitigated hydrologic separation, in particular, the lakefront separation condition.

E.12 RISK ANALYSIS

GLMRIS deals with the risks of the transfer of invasive species by hydraulic pathway connections. USACE guidance is readily available to quantify risk for flood control projects. The risk of a flood overtopping or bypassing a hydraulic separation barrier, for example, is directly related to the risk of a levee overtopping at the same height. For GLMRIS, USACE risk guidance for flood control projects will be used to quantify the risk for the economic analysis as well as the risk of overtopping and bypassing project-condition hydraulic separation barriers (project condition). The risk analysis for potential overtopping or bypassing of hydraulic barriers will be developed and documented in the with-project-condition report. The purpose of this baseline and future without-project risk analysis is to characterize model uncertainty and define the exceedance probability function for the economic analysis of the without-project condition. It also demonstrates that the risk of transfer of invasive species by hydraulic pathway connections is limited to the known connections from the CSSC to the NSC, Chicago River, Calumet River, Grand Calumet River, and Little Calumet River. The hydrologic and hydraulic modeling involved in GLMRIS is extensive and complex. The best available models were utilized to develop the hydrology and hydraulics for the CAWS modeling. The models and their interrelations are outlined elsewhere in this appendix. Also, calibration and verification of the models has been documented elsewhere.

Traditional hydrologic and hydraulic risk analysis methods used for natural dendritic river systems cannot be applied to the CAWS. Most of the CAWS channels are man-made, and the system is highly regulated. There are four main outlets to the CAWS, unlike a dendritic system, which would have only one; three of these outlets also function as inlets in low-flow conditions. Also, during low-flow conditions, the CAWS is basically maintained as a level pool. During floods, these outlets are controlled by human decisions, based on precipitation forecasts and real-time decisions based on the CAWS levels at sensing points as provided in the waterway operation manuals. Peak stages on the CAWS can be significantly affected by the timing of these operations. These operations significantly change the directions of flow during a flood event in such a way that peak flows have little relation to peak stages. Figures E.26 through E.31 present flow and stage hydrographs for the 100-year baseline condition HEC-RAS unsteady flow model for various locations throughout the CAWS.

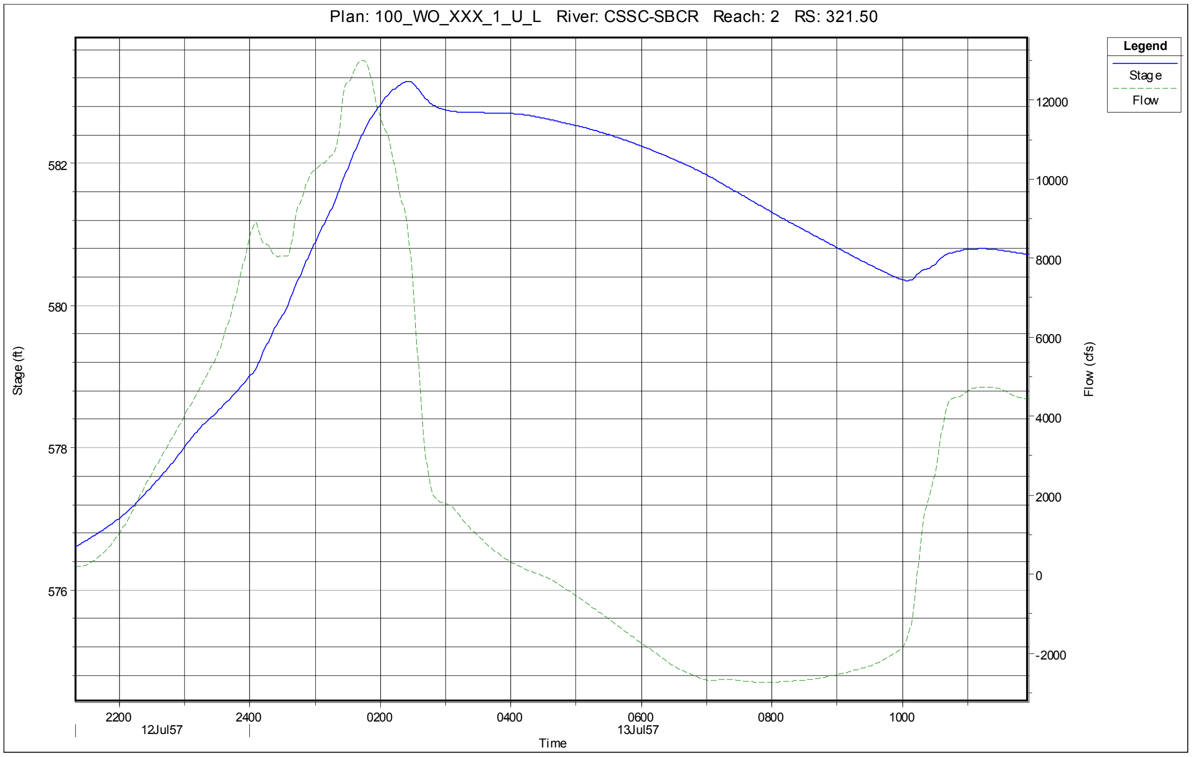

FIGURE E.26 Flow and Stage Hydrograph for the CSSC – South Branch of the Chicago River, Reach 2, River Mile 321.50

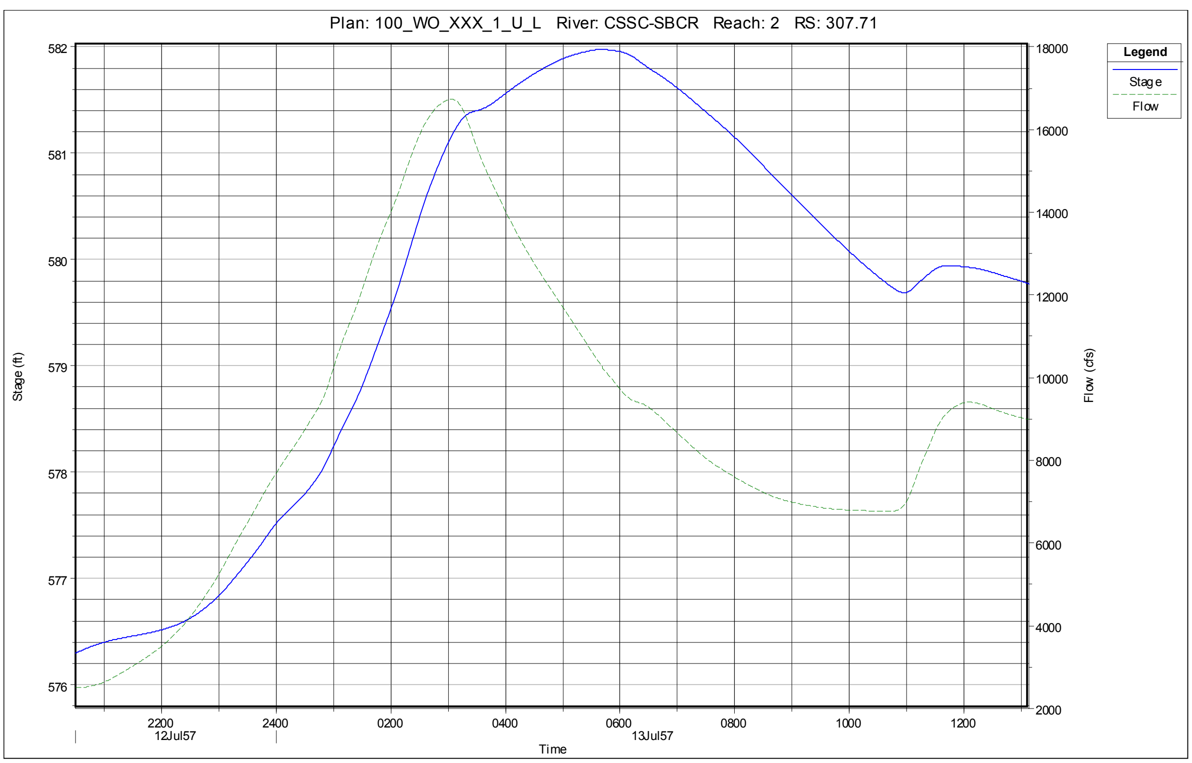

FIGURE E.27 Flow and Stage Hydrograph for the CSSC – South Branch of the Chicago River, Reach 2, River Mile 307.71

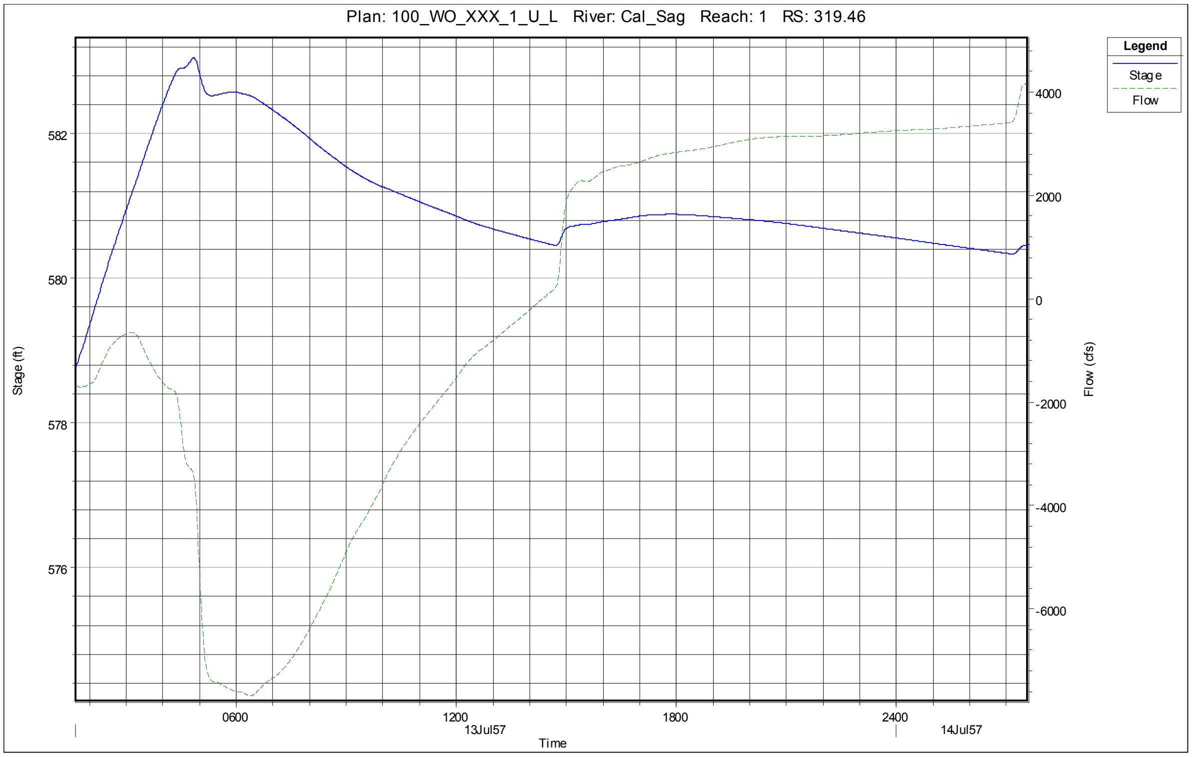

FIGURE E.28 Flow and Stage Hydrograph for the Cal-Sag Channel, Reach 1, River Mile 319.46

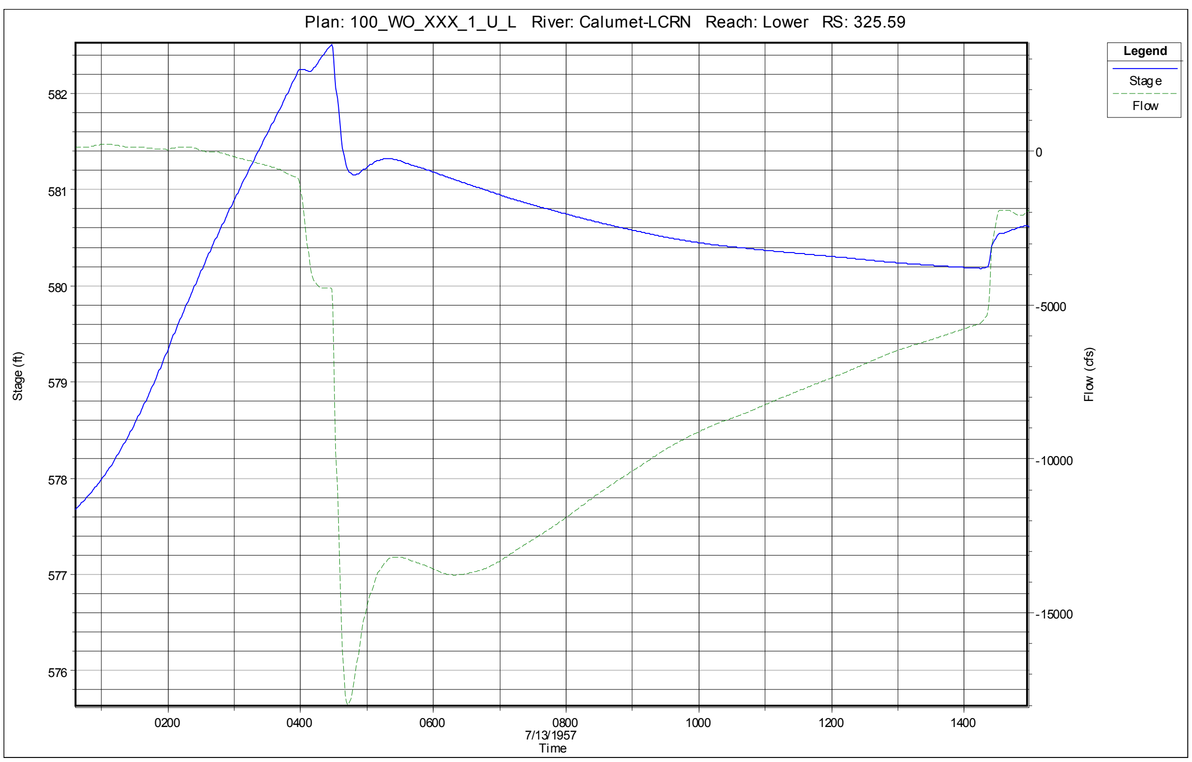

FIGURE E.29 Flow and Stage Hydrograph for the Calumet River – Little Calumet River North, Reach Lower, River Mile 325.59

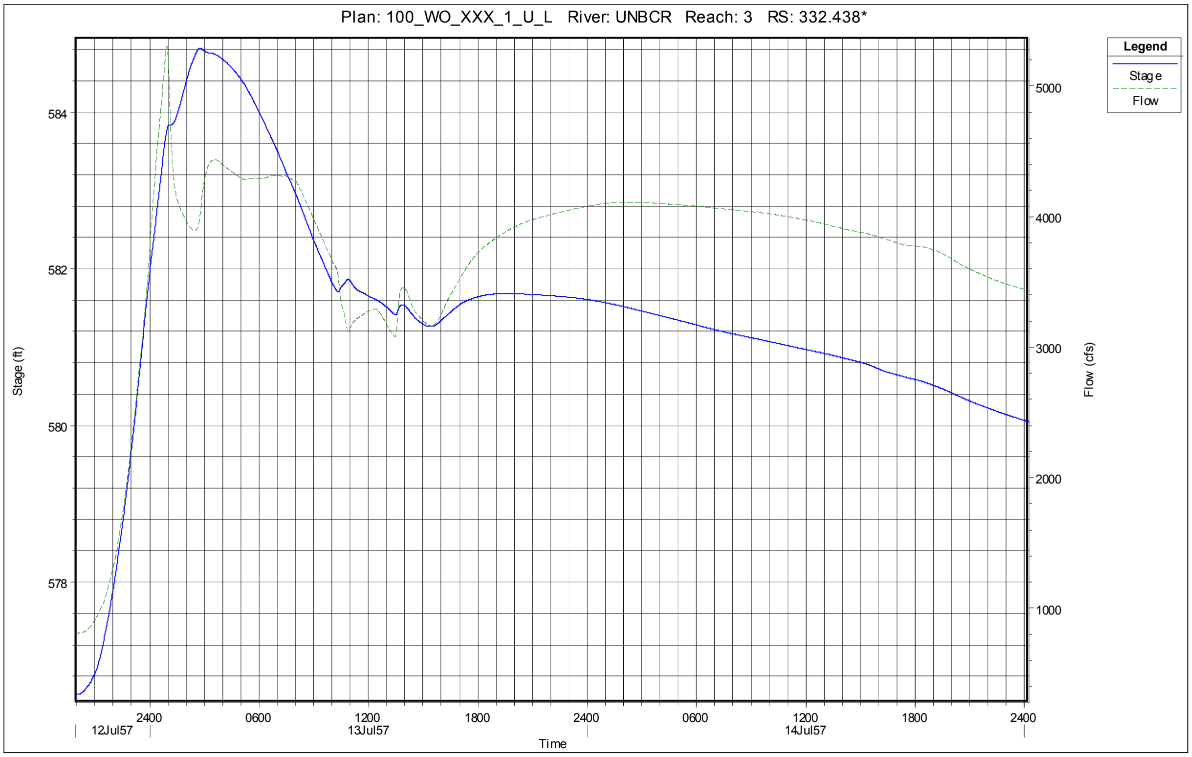

FIGURE E.30 Flow and Stage Hydrograph for the Upper North Branch of the Chicago River, Reach 3, River Mile 332.438

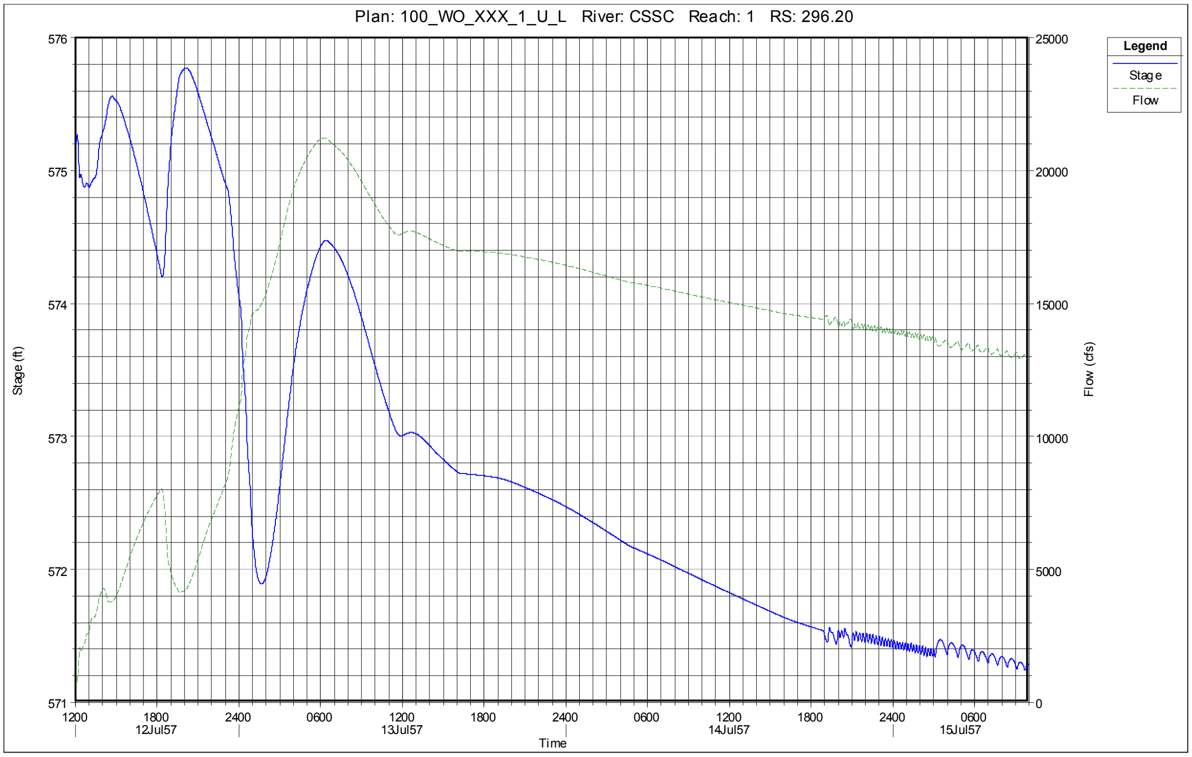

FIGURE E.31 Flow and Stage Hydrograph for the CSSC, Reach 3, River Mile 296.20

As shown in Figures 26–31, unique stage-discharge rating curves do not apply to the CAWS.

Record historic flow frequency data for the relevant period are not available for the majority of the CAWS, with the exception of the gage information at Lockport. Also, record stage frequency data for the relevant period are unavailable for the majority of the CAWS.

Although the CAWS is a complex system and the modeling of the CAWS is very complex as well, the verification of the modeling shows that it is a very relevant and valuable tool in providing reasonable predictions of maximum stages along the CAWS.

The manual "Engineering and Design: Risk-Based Analysis for Flood Damage Reduction Studies" states that, "A graphical approach is used when the sample of gauge records is small and incomplete. Examples are regulated flows, mixed populations such as generalized rainfall…events…" Table 4-5 in the manual provides guidelines for selecting the equivalent record length based on the method of frequency function estimation. For the CAWS, the method "Estimated with rainfall runoff routing model with handbook or textbook model parameters" was selected. Also, the subscript in the table states, "Based on judgment to account for the quality of any data used in the analysis, for the degree of confidence in models, and for previous experience with similar studies." Thus, it is appropriate to select the higher end of the range, 15 years, because of the extensive calibration and verification of the modeling.

Section 5-7, "Sensitivity Analysis and Professional Judgment," provides guidance for using upper and lower limits as a guide for estimating the standard deviation of stage uncertainty. Because of the lack of unique stage-discharge relationships and the highly regulated nature of the CAWS, as outlined above, regulation is the most dominant factor in stage uncertainty on the CAWS.

Figure E.32, showing Chicago Lock operations for the July 2010 flood event, presents just how highly efficient the Chicago Lock is in providing flood relief. The timing of human decisions, when opening just one side of the lock (opened 50%), can have a significant impact on stages. Also, high-water-mark data are available for a recent historic event that was described in the verification report regarding the September 2008 flood event, "Chicago Area Waterway System, September 2008 Storm Event Model Verification" (see tables E.17 and E.18 below) that can be used to inform the GLMRIS flood risk analysis. A detailed look at Figure E.33, also taken from the report, provides important verification of the TNET hydrology, which is the predominant inflow in the CAWS, particularly in the critical areas near downtown Chicago. Figure E.34 presents a more detailed look at the model flow hydrograph, with rules, of the observed flow at the same location, along with the flow hydrograph at the Albany Avenue gage on the North Branch of the Chicago River, which is the only other inflow north of the Grand Avenue gage. Note how well the modeled flow with rules compares to the observed flow and also the relative contribution of the North Branch of the Chicago River as compared to the total flow. This provides an important piece of information regarding the verification of the TNET inflows at a very important geographic and economic location for GLMRIS.

TABLE E.17 Historic versus Model Stages Using Operator's Logs

Locations	Gauge ID	Minimum or Maximum Stage (ft)		
		Modeled	Observed	Delta
NSC Wilmette	EWILMTTN	582.88	584.17	−1.29
North Branch – Albany	NBALBANY	589.19	588.25	0.94
North Branch – Lawrence Ave.	*NBLAWRNCE*	584.73	583.02	1.71
Chicago River at Chicago Lock	*USGS 05536121*	581.79	582.45	−0.66
South Branch Willow Springs	WILLOWSPR	581.17	581.85	−0.68
CSSC – Lemont	*USGS 05536890*	579.97	580.60	−0.63
CSSC – Lockport Canal	LPCANAL	569.84	569.41	0.43
CSSC Lockport Powerhouse	MVR	568.36	568.89	−0.53
Cal Sag Channel	CALSAGCH	582.01	582.62	−0.61
Calumet River upstream of O'Brien	MVR	582.24	582.91	-0.67
Calumet River downstream of O'Brien	MVR	580.43	579.92	0.51

TABLE E.18 Historic versus Model Stages Using Rules

Locations	Gauge ID	Minimum or Maximum Stage (ft)		
		Modeled	Observed	Delta
NSC Wilmette	EWILMTTN	584.21	584.17	0.04
North Branch – Albany	NBALBANY	589.19	588.25	0.94
North Branch – Lawrence Ave.	*NBLAWRNCE*	584.16	583.02	1.14
Chicago River at Chicago Lock	*USGS 05536121*	582.48	582.45	0.03
South Branch Willow Springs	WILLOWSPR	581.98	581.85	0.13
CSSC – Lemont	*USGS 05536890*	580.58	580.60	−0.02
CSSC – Lockport Canal	LPCANAL	570.70	569.41	1.29
CSSC Lockport Powerhouse	MVR	568.49	568.89	−0.4
Cal-Sag Channel	CALSAGCH	581.99	582.62	−0.63
Calumet River upstream of O'Brien	MVR	582.50	582.91	−0.41
Calumet River downstream of O'Brien	MVR	580.37	579.92	0.45

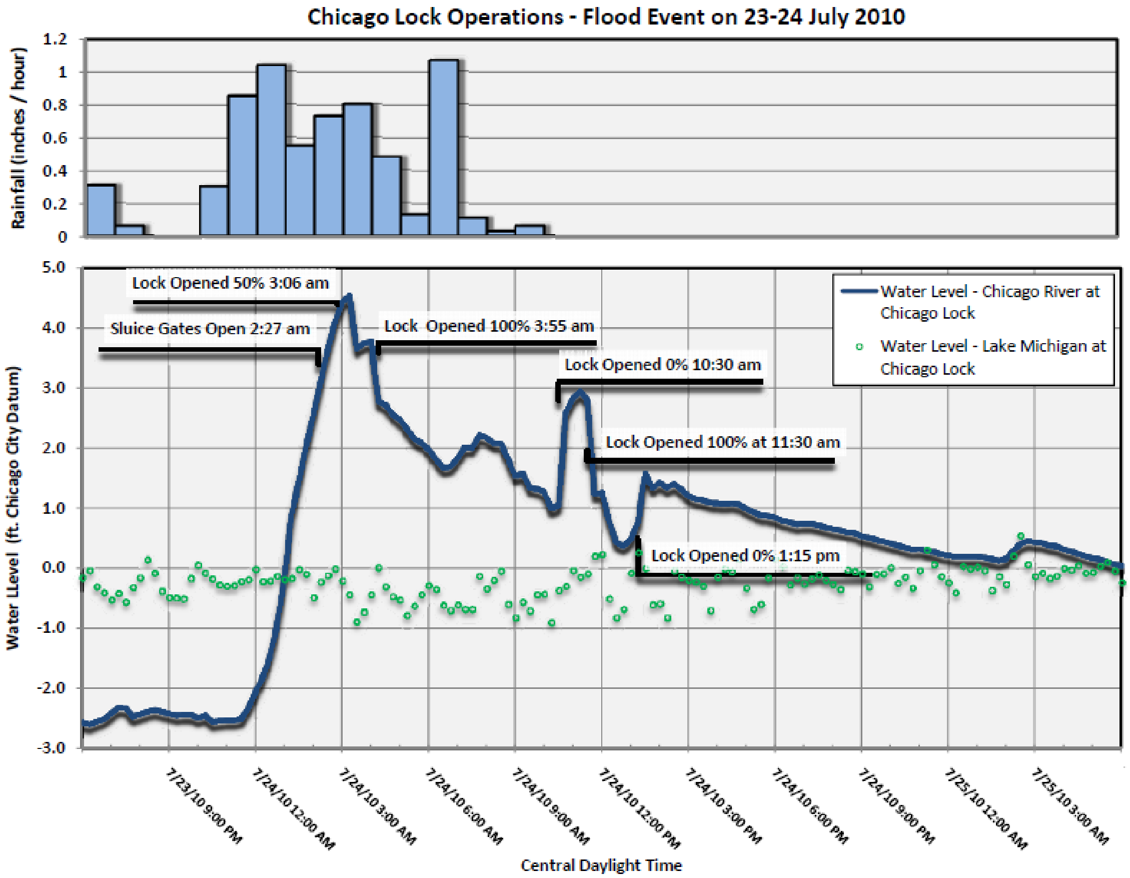

FIGURE E.32 Lock Operations during the July 2010 Flood Event

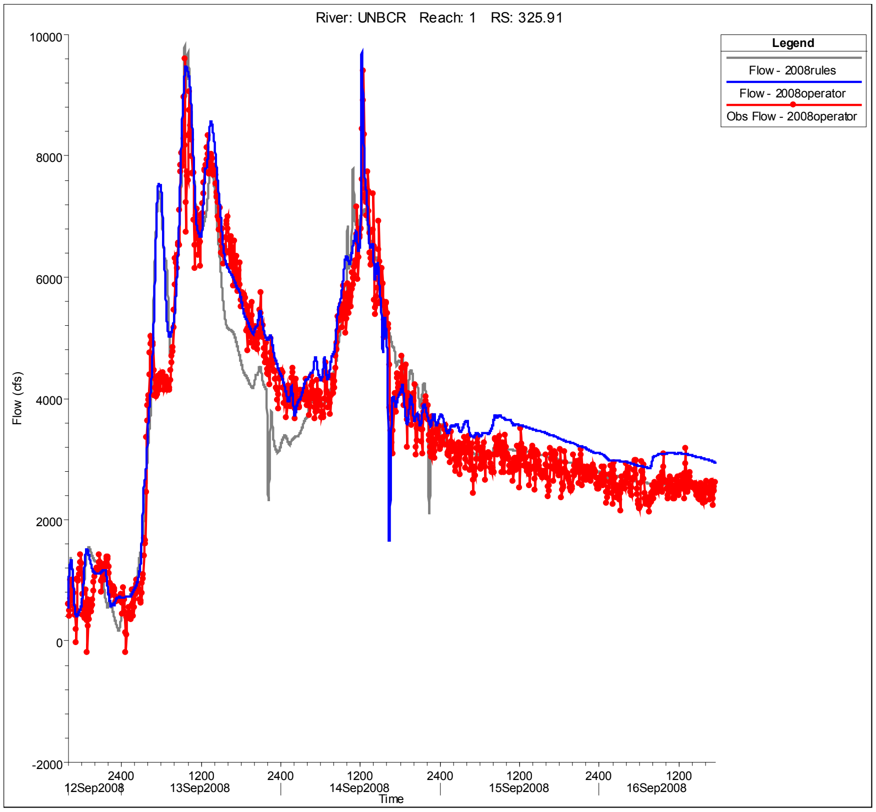

FIGURE E.33 Flow on North Branch of Chicago River at Grand Avenue (USGS 05536118)

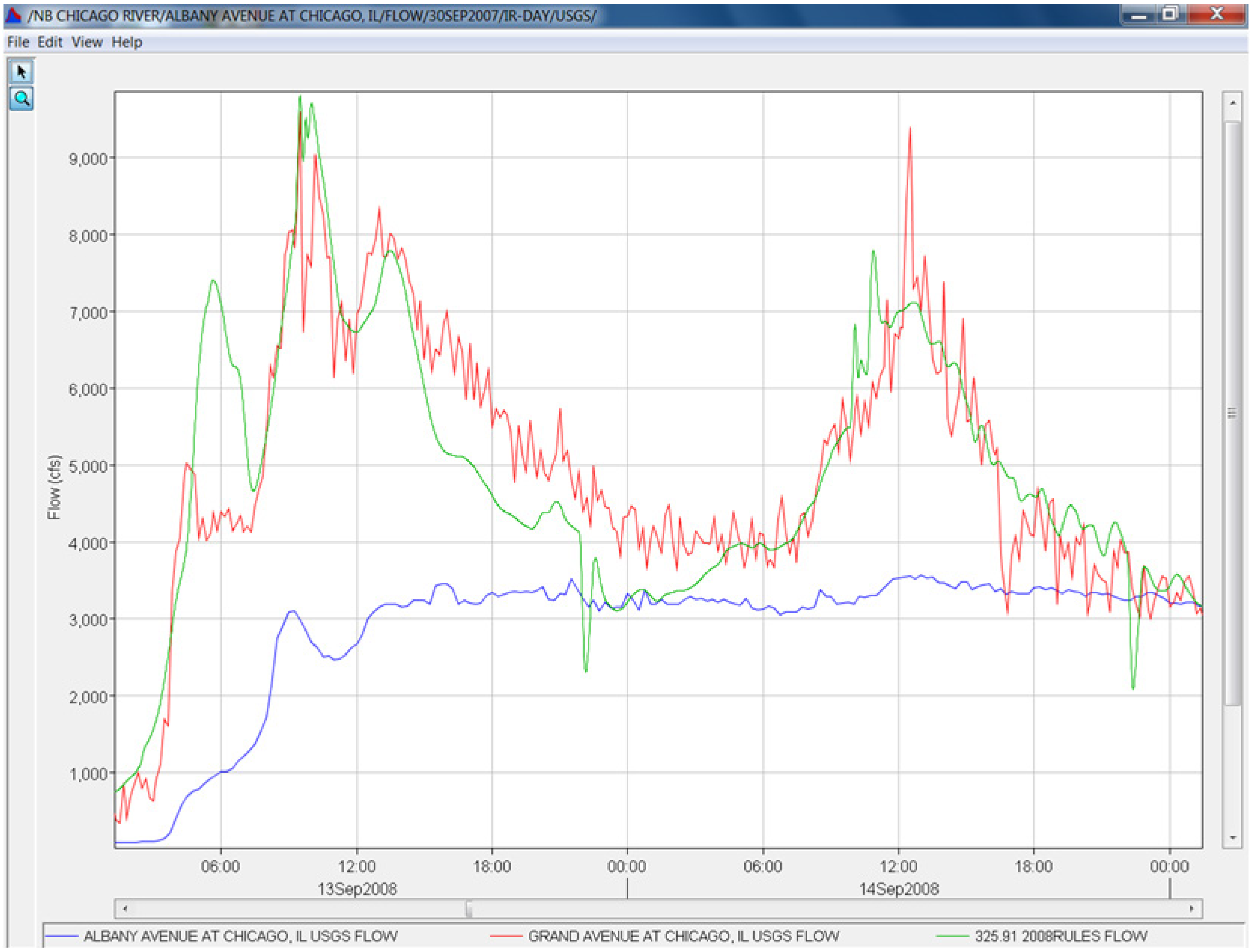

FIGURE E.34 Flow on North Branch of Chicago River at Grand Avenue (USGS 05536118), Albany Avenue (USGS 05536105), and Modeled with Rules

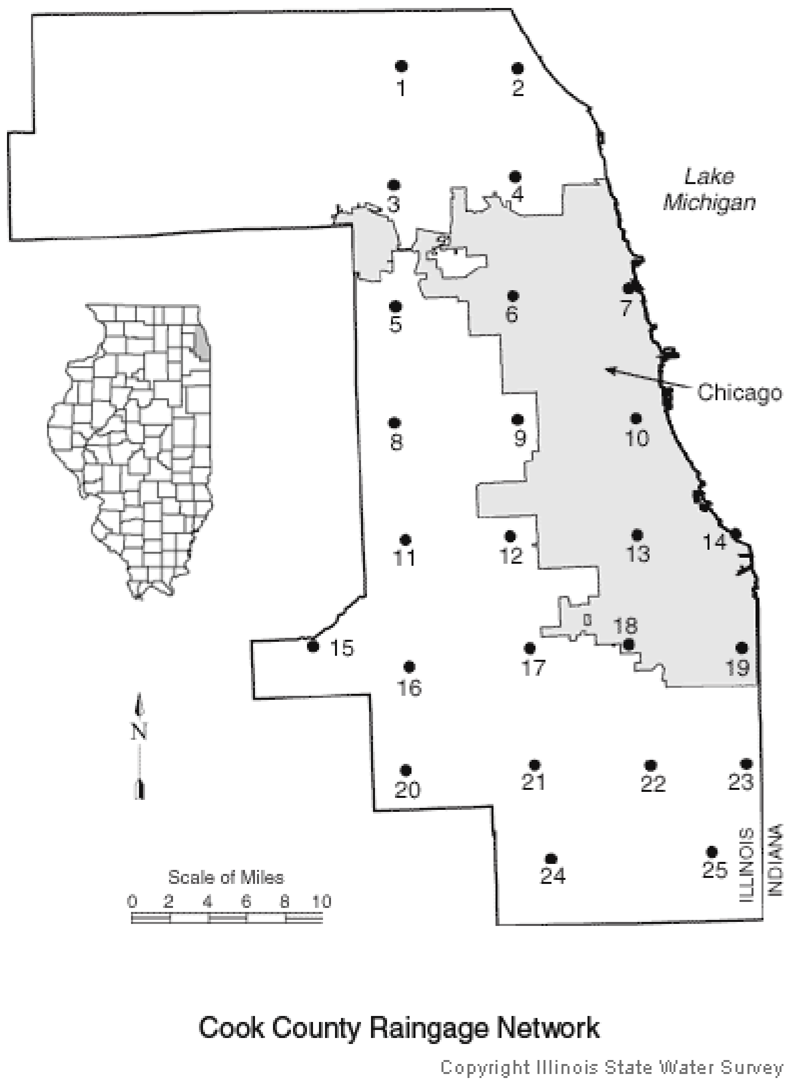

FIGURE E.35 Cook County Raingage Network

Gages 7 and 10 from the Cook County raingage network, as shown in Figure E.35, averaged 4.5 in. of precipitation over a 48-hr period during the September 2008 flood event. The rainfall in the raingage network basin translates to somewhere between a 10% and 1% chance exceedance flood event (ISWS 2009).

The HEC-FDA model was run for various locations on the CAWS to examine the upper and lower range of confidence limits for comparison with available calibration and verification data along the CAWS. This FDA model is independent of the overall HEC-FDA model developed for the economic analysis. The index cross sections for this model were selected to analyze project performance at project hydraulic separation locations. However, even when analyzing project performance, the HEC-FDA model requires economic input simply to run the program. Dummy economic input was created so that the project performance analysis could be performed. This model also informs the economic model, as the only outstanding hydraulic and hydrologic input variable for running the economic HEC-FDA model is the equivalent record length.

The maximum absolute spread between computed and observed values from Tables E.17 and E.18 is 1.29 feet (these values exclude the Lawrence Avenue gage, which is well known to be unreliable) or an estimate of approximately 2 ft for the 95% of the stage uncertainty range, which translates to a standard deviation of 0.5 ft. Note from the lock operations graph for the July 2010 flood event, opening one side of the lock translated to approximately 1 ft of stage reduction, which would equal two standard deviations to put it in perspective. Since the September 2008 flood event was estimated to be between a 10 and 1% chance exceedance, this gives another point of reference when comparing the HEC-FDA Table E.19 and Tables E.17 and E.18 from the 2008 flood verification report.

TABLE E.19 Exceedance Probability Functions with Uncertainty from HEC-FDA Model

Exceedance Probability	Baseline Without Project: Mean Stage (ft)	Baseline Without Project: Confidence Limits -2 SD	-1 SD	+1 SD	+2 SD	Future Without Project: Mean Stage (ft.)	Future Without Project: Confidence Limits −2 SD	−1 SD	+1 SD	+2 SD
Chicago River										
0.500	579.8	579.0	579.4	580.2	580.6	577.0	576.8	576.9	577.0	577.1
0.300	580.7	579.5	580.1	581.3	581.9	577.1	576.8	577.0	577.2	577.4
0.200	581.3	580.0	580.6	581.9	582.6	577.2	576.8	577.0	577.4	577.5
0.100	582.3	581.1	581.7	582.9	583.5	577.5	577.1	577.3	577.7	578.0
0.040	582.7	581.5	582.1	583.3	583.9	577.9	577.3	577.6	578.2	578.5
0.020	582.8	581.6	582.2	583.4	584.0	579.6	578.5	579.0	580.1	580.6
0.010	582.9	581.7	582.3	583.5	584.0	581.0	579.6	580.3	581.8	582.5
0.004	583.1	581.9	582.5	583.7	584.3	582.1	580.3	581.2	582.9	583.8
0.002	583.3	582.1	582.7	583.9	584.4	582.8	580.8	581.8	583.7	584.7
0.001	583.4	582.3	582.9	584.0	584.6	583.4	581.3	582.4	584.5	585.6
Cal-Sag Channel										
0.500	578.3	577.7	578.0	578.7	579.0	577.9	577.6	577.7	578.1	578.3
0.300	579.1	578.0	578.6	579.7	580.3	578.4	577.6	578.0	578.7	579.1
0.200	579.6	578.3	579.0	580.3	581.0	578.6	577.7	578.2	579.1	579.5
0.100	580.7	578.9	579.8	581.7	582.6	579.4	578.2	578.8	580.0	580.6
0.040	581.8	579.5	580.6	582.9	584.0	580.5	578.8	579.6	581.3	582.2
0.020	582.8	580.0	581.4	584.1	585.5	582.4	579.9	581.1	583.6	584.9
0.010	583.2	580.3	581.8	584.7	586.2	583.0	580.2	581.6	584.3	585.7
0.004	584.3	580.9	582.6	586.0	587.7	583.9	580.8	582.4	585.5	587.1
0.002	585.0	581.3	583.2	586.9	588.8	584.6	581.2	582.9	586.3	588.1
0.001	585.7	581.7	583.7	587.8	589.8	585.2	581.5	583.4	587.1	589.0

TABLE E.19 Exceedance Probability Functions with Uncertainty from HEC-FDA Model (Cont.)

Exceedance Probability	Baseline Without Project					Future Without Project				
	Mean Stage (ft.)	Confidence Limits				Mean Stage (ft.)	Confidence Limits			
		−2 SD	−1 SD	+1 SD	+2 SD		−2 SD	−1 SD	+1 SD	+2 SD
Calumet-Little Calumet River-N Lower										
0.500	578.5	577.9	578.2	578.9	579.2	578.1	577.7	577.9	578.3	578.5
0.300	579.3	578.1	578.7	579.9	580.5	578.6	577.8	578.2	578.9	579.3
0.200	579.8	578.4	579.1	580.4	581.1	578.8	577.9	578.4	579.3	579.8
0.100	580.9	579.9	580.4	581.4	581.9	579.6	578.7	579.2	580.0	580.4
0.040	581.9	581.2	581.5	582.3	582.7	580.7	580.0	580.4	581.1	581.4
0.020	582.5	581.9	582.2	582.8	583.1	582.2	581.6	581.9	582.5	582.8
0.010	582.6	582.0	582.3	582.9	583.2	582.5	582.0	582.2	582.8	583.1
0.004	582.6	582.0	582.3	582.9	583.2	582.5	582.0	582.2	582.8	583.1
0.002	582.7	582.1	582.4	582.9	583.2	582.5	582.0	582.2	582.8	583.1
0.001	582.7	582.1	582.4	583.0	583.2	582.5	582.0	582.3	582.8	583.1
CSSC-South Branch of Chicago River Bubbly										
0.500	579.6	578.8	579.2	580.0	580.4	576.9	576.7	576.8	576.9	577.0
0.300	580.5	579.3	579.9	581.2	581.8	577.0	576.8	576.9	577.2	577.3
0.200	581.1	579.8	580.4	581.8	582.4	577.1	576.8	576.9	577.3	577.5
0.100	582.2	580.6	581.4	582.9	583.7	577.4	577.0	577.2	577.7	577.9
0.040	582.7	581.0	581.9	583.6	584.4	577.9	577.3	577.6	578.2	578.4
0.020	583.0	581.3	582.1	583.9	584.8	579.5	578.5	579.0	580.1	580.6
0.010	583.2	581.4	582.3	584.0	584.9	581.0	579.6	580.3	581.8	582.5
0.004	583.7	581.8	582.8	584.7	585.7	582.1	580.3	581.2	583.0	583.9
0.002	584.2	582.1	583.1	585.2	586.2	582.9	580.9	581.9	583.9	584.9
0.001	584.5	582.4	583.5	585.6	586.6	583.6	581.4	582.5	584.7	585.8

TABLE E.19 Exceedance Probability Functions with Uncertainty from HEC-FDA Model (Cont.)

Exceedance Probability	Baseline Without Project					Future Without Project				
	Mean Stage (ft.)	Confidence Limits				Mean Stage (ft.)	Confidence Limits			
		-2 SD	-1 SD	+1 SD	+2 SD		-2 SD	-1 SD	+1 SD	+2 SD
CSSC-South Branch of Chicago River Middle										
0.500	579.2	578.5	578.8	579.5	579.8	576.8	576.6	576.7	576.8	576.9
0.300	580.0	578.8	579.4	580.5	581.1	577.0	576.7	576.8	577.1	577.3
0.200	580.5	579.2	579.8	581.1	581.7	577.1	576.7	576.9	577.3	577.4
0.100	581.5	579.9	580.7	582.3	583.1	577.3	576.9	577.1	577.5	577.8
0.040	582.1	580.3	581.2	583.0	583.9	577.8	577.2	577.5	578.1	578.4
0.020	582.4	580.5	581.4	583.4	584.3	579.5	578.4	579.0	580.0	580.6
0.010	582.6	580.6	581.6	583.6	584.6	581.0	579.5	580.2	581.7	582.4
0.004	583.5	581.2	582.4	584.7	585.8	582.1	580.3	581.2	583.0	583.9
0.002	584.2	581.6	582.9	585.4	586.7	582.9	580.9	581.9	583.9	584.9
0.001	584.8	582.0	583.4	586.1	587.5	583.6	581.4	582.5	584.7	585.8
Little Calumet River-N1										
0.500	578.5	577.8	578.2	578.9	579.2	578.1	577.7	577.9	578.3	578.5
0.300	579.3	578.1	578.7	579.9	580.5	578.6	577.8	578.2	578.9	579.3
0.200	579.8	578.4	579.1	580.4	581.1	578.8	577.9	578.4	579.3	579.8
0.100	580.9	580.0	580.5	581.4	581.8	579.6	578.7	579.2	580.0	580.4
0.040	581.9	581.4	581.7	582.2	582.4	580.7	580.0	580.4	581.1	581.4
0.020	582.5	582.2	582.3	582.6	582.8	582.2	581.6	581.9	582.5	582.8
0.010	582.5	582.2	582.3	582.6	582.8	582.5	581.9	582.2	582.8	583.0
0.004	582.5	582.2	582.3	582.7	582.8	582.5	582.0	582.2	582.8	583.0
0.002	582.5	582.2	582.3	582.7	582.8	582.5	582.0	582.2	582.8	583.0
0.001	582.5	582.2	582.4	582.7	582.8	582.5	582.0	582.2	582.8	583.0

TABLE E.19 Exceedance Probability Functions with Uncertainty from HEC-FDA Model(Cont.)

	Baseline Without Project					Future Without Project				
		Confidence Limits					Confidence Limits			
Exceedance Probability	Mean Stage (ft.)	−2 SD	−1 SD	+1 SD	+2 SD	Mean Stage (ft.)	−2 SD	−1 SD	+1 SD	+2 SD
Little Calumet West										
0.500	593.9	593.2	593.5	594.2	594.5	593.9	593.2	593.5	594.2	594.5
0.300	594.6	593.5	594.1	595.2	595.8	594.6	593.5	594.1	595.2	595.8
0.200	595.1	593.8	594.4	595.8	596.5	595.1	593.8	594.4	595.8	596.5
0.100	596.2	594.3	595.3	597.1	598.0	596.2	594.3	595.3	597.1	598.0
0.040	597.6	595.2	596.4	598.9	600.1	597.6	595.2	596.4	598.9	600.1
0.020	598.6	595.7	597.2	600.1	601.5	598.6	595.7	597.2	600.1	601.6
0.010	599.4	596.2	597.8	601.0	602.6	599.4	596.2	597.8	601.0	602.6
0.004	600.4	596.7	598.6	602.3	604.1	600.4	596.7	598.6	602.3	604.1
0.002	601.2	597.1	599.1	603.2	605.2	601.2	597.2	599.2	603.2	605.2
0.001	601.8	597.5	599.7	604.0	606.1	601.9	597.5	599.7	604.0	606.2
North Shore Channel										
0.500	584.2	584.2	584.2	584.2	584.2	578.8	577.8	578.2	579.3	579.8
0.300	584.2	584.2	584.2	584.2	584.2	580.2	578.2	579.2	581.2	582.2
0.200	584.2	584.2	584.2	584.2	584.2	581.0	578.8	579.9	582.2	583.3
0.100	584.2	584.2	584.2	584.2	584.3	582.9	581.9	582.4	583.4	583.9
0.040	584.3	584.2	584.2	584.3	584.3	584.2	584.0	584.1	584.3	584.4
0.020	584.3	584.3	584.3	584.3	584.3	584.2	584.0	584.1	584.3	584.4
0.010	584.3	584.3	584.3	584.3	584.3	584.2	584.0	584.1	584.3	584.4
0.004	584.3	584.3	584.3	584.3	584.3	584.2	584.0	584.1	584.3	584.4
0.002	584.3	584.3	584.3	584.3	584.3	584.2	584.1	584.1	584.3	584.4
0.001	584.3	584.3	584.3	584.3	584.3	584.2	584.1	584.1	584.3	584.4

TABLE E.19 Exceedance Probability Functions with Uncertainty from HEC-FDA Model (Cont.)

Exceedance Probability	BASELINE WITHOUT PROJECT Mean Stage (ft.)	Confidence Limits -2 SD	-1 SD	+1 SD	+2 SD	FUTURE WITHOUT PROJECT Mean Stage (ft.)	Confidence Limits -2 SD	-1 SD	+1 SD	+2 SD
UN Br Chicago River										
0.500	582.0	581.4	581.7	582.3	582.6	578.3	578.0	578.2	578.5	578.7
0.300	582.6	581.8	582.2	583.0	583.4	578.7	577.9	578.3	579.2	579.6
0.200	583.0	582.1	582.5	583.4	583.8	579.0	577.8	578.4	579.6	580.2
0.100	583.5	582.5	583.0	584.1	584.6	579.9	578.3	579.1	580.6	581.4
0.040	584.0	582.8	583.4	584.6	585.2	582.2	579.6	580.9	583.5	584.7
0.020	584.8	583.4	584.1	585.4	586.1	583.5	580.3	581.9	585.1	586.7
0.010	585.0	583.6	584.3	585.8	586.5	583.9	580.6	582.3	585.6	587.3
0.004	585.5	583.9	584.7	586.3	587.1	584.5	580.9	582.7	586.3	588.1
0.002	585.8	584.1	584.9	586.6	587.5	584.9	581.1	583.0	586.8	588.6
0.001	586.1	584.3	585.2	586.9	587.8	585.3	581.3	583.3	587.2	589.2

E.13 REFERENCES

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ENCLOSURE A

CRITICAL DURATION FOR OVERBANK FLOODING

Table 1 – Critical Duration on CAWS

	NSC	NBCR			Chicago River	SBCR	CSSC		Calumet River Upper
		Upper	Middle	Lower			Upper	Lower	
EXISTING	48	48	24	12	12	12	12	24	24
FUTURE	48	48	24	24	24	24	24	24	24

	LCR North	Cal-Sag Channel		WB GCR	
		Upper	Lower	East	West
EXISTING	24	24	24	24	48
FUTURE	24	24	12	24	48

Figure 1 – Critical Duration on the CAWS for the Future Condition (RED: 24-hour critical, GREEN: 12-hour critical, BLUE: 48-hour critical)

Based on the modeling results the preliminary findings included:

1) the 3-hour duration was not critical in any location for both existing and future conditions and can be eliminated from further consideration for the overbank critical duration analysis;

2) the 48-hour duration was critical for only three reaches for both existing and future conditions (NSC, W. WB GCR and the upper branch of the NBCR); and

3) In overall, the 24-hour duration seems predominant although 12-hour duration is critical near downtown areas which may have more economic impacts.

By taking into account the flood elevation and channel geometry regarding the 48-hour critical duration reaches additional findings are:

1) For the NSC, the 100 yr flood per the topography appears to stay in bank for all durations, so overbank damages should be minimal. The 12 hr duration is significantly lower than the 24 and 48 hr durations for the future condition, which leaves the 24 and 48 hr durations, which are minimally different (approx. 0.2 ft max difference for existing condition, approximately equal for future condition). From this information the 24 hour is a reasonable choice for the NSC.

2) For the WB GRC west, it is similar to the NSC in that the 100 yr flood appears to stay for the most part in bank per the topography. Also, maximum stages are nearly equal for all durations and conditions, so the 24 hr is a reasonable choice for this reach.

3) For the upper branch of the NBCR the 12 hr duration is approximately one foot lower than 48 hr duration the for the future condition and approximately one and a half feet lower for the existing condition which leaves the 24 and 48 hr durations. While the 48 hr is more than half a foot higher than the 24 hr for the future condition, it is only a couple of tenths of a foot lower for the existing condition. This area may also stay largely in bank, so the 24 hr is a reasonable choice for the upper branch of the NBCR.

4) It is reasonable to select the 24 hr duration for the 48 hr duration critical reaches.

By taking into account the flood elevation and channel geometry regarding the 12-hour critical duration reaches additional findings are:

1) For the future condition, only the Lower Cal-Sag Channel was critical for the 12 hr duration. For this reach the stage difference between the 48 hr and 24 hr is insignificant. This whole reach should stay largely in bank, so should have minimal economic impacts. Based on this information, the 24 hour duration is a reasonable choice for the Lower Cal-Sag Channel. Based on the information above the 24 hr duration is the most reasonable choice for the future condition.

2) The existing condition 12 hr critical duration reaches include: the Lower NBCR, Chicago River, SBCR and the Upper CSSC. There is no significant difference between stages for all of these reaches, with the exception of the last reach, the Upper CSSC, and for that reach only a maximum difference of approximately three tenths of a foot. Based on this information, the 24 hr appears to be a reasonable choice for the critical duration for the CAWS system for the existing condition, also.

In summary, the 24 hr duration appears to be the most reasonable assumption for the CAWS overbank model, and it would be used in the final modeling runs.

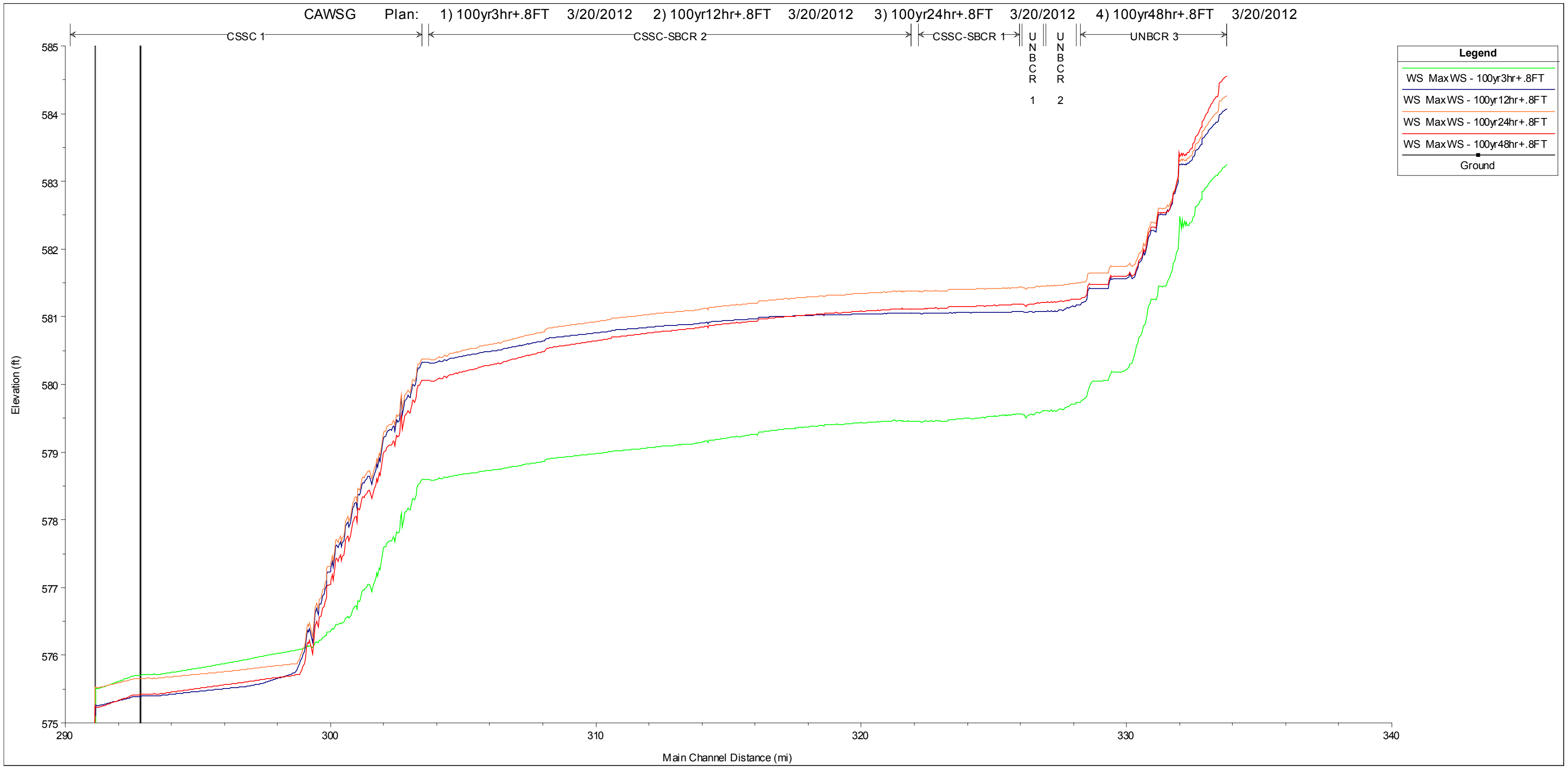

Figure 1 - Maximum water surface elevation from Lockport to NSC confluence (Future)
24 hr critical except 48 hr critical upper reach of NBCR

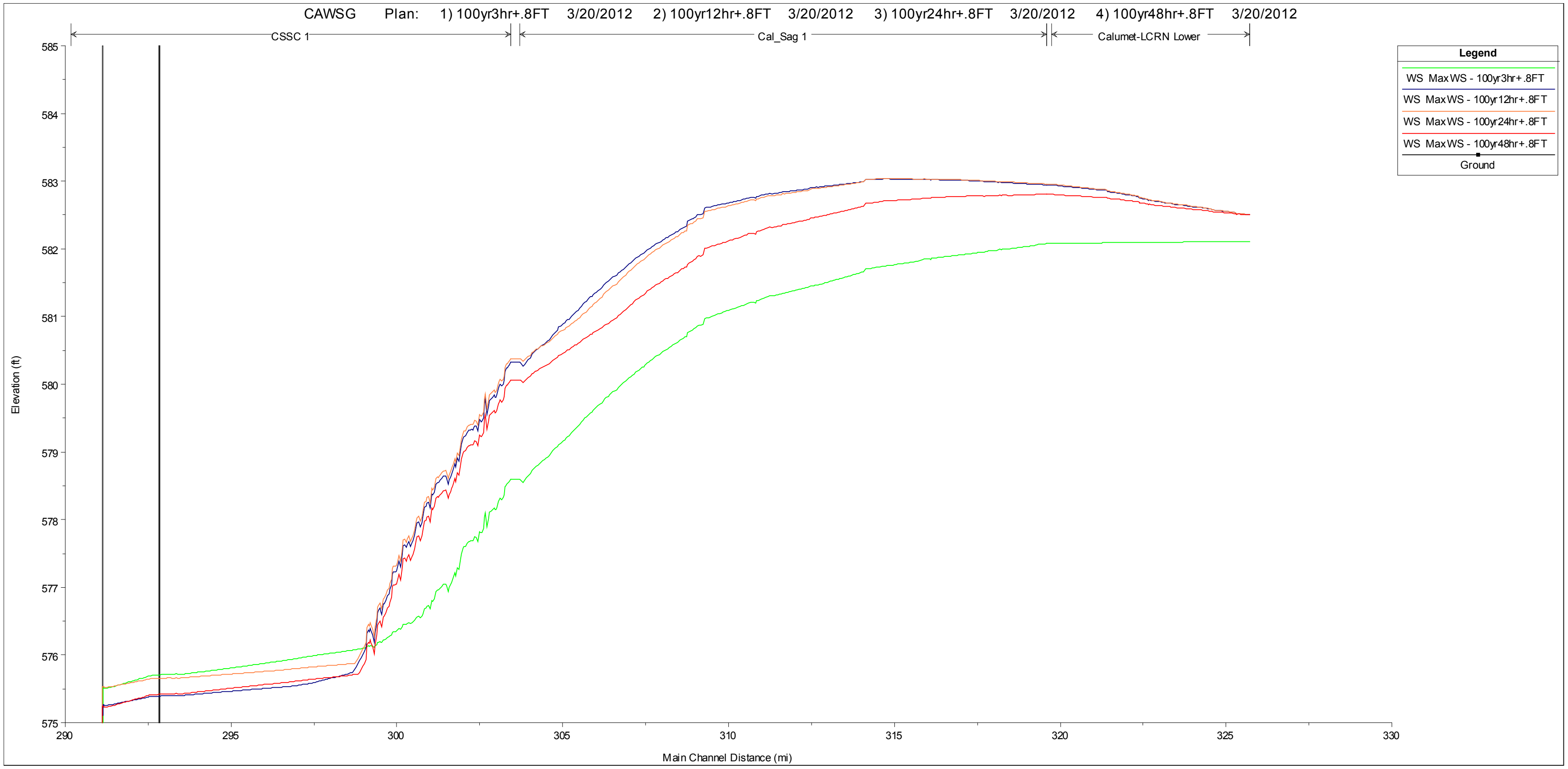

Figure 2 - Maximum water surface elevation from Lockport to O'Brien Lock and Dam (Future)
24 hr critical except 12 hr critical for lower half of Cal-Sag Channel

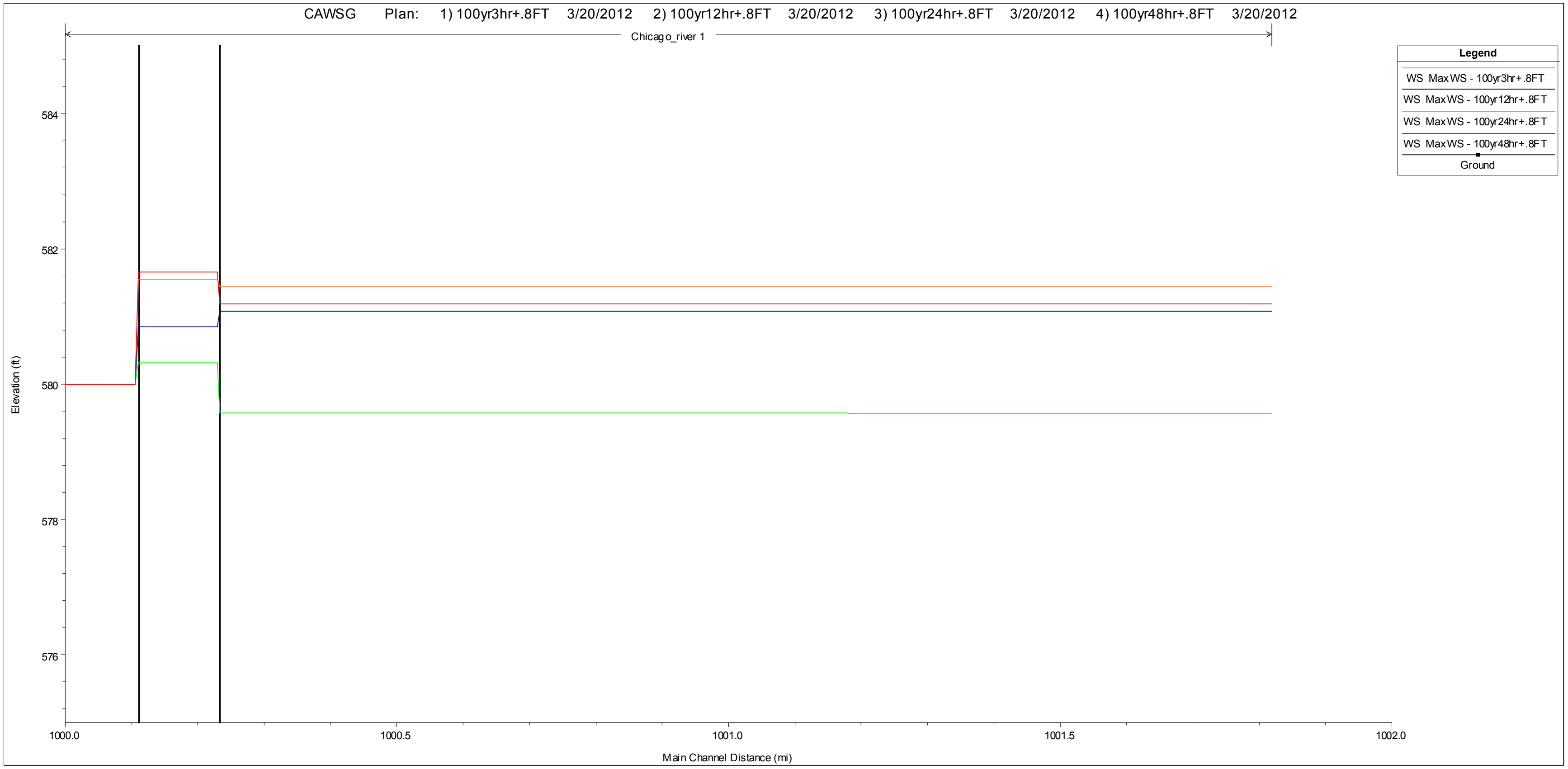

Figure 3 - Maximum water surface elevation on Chicago River (Future)
24 hr critical

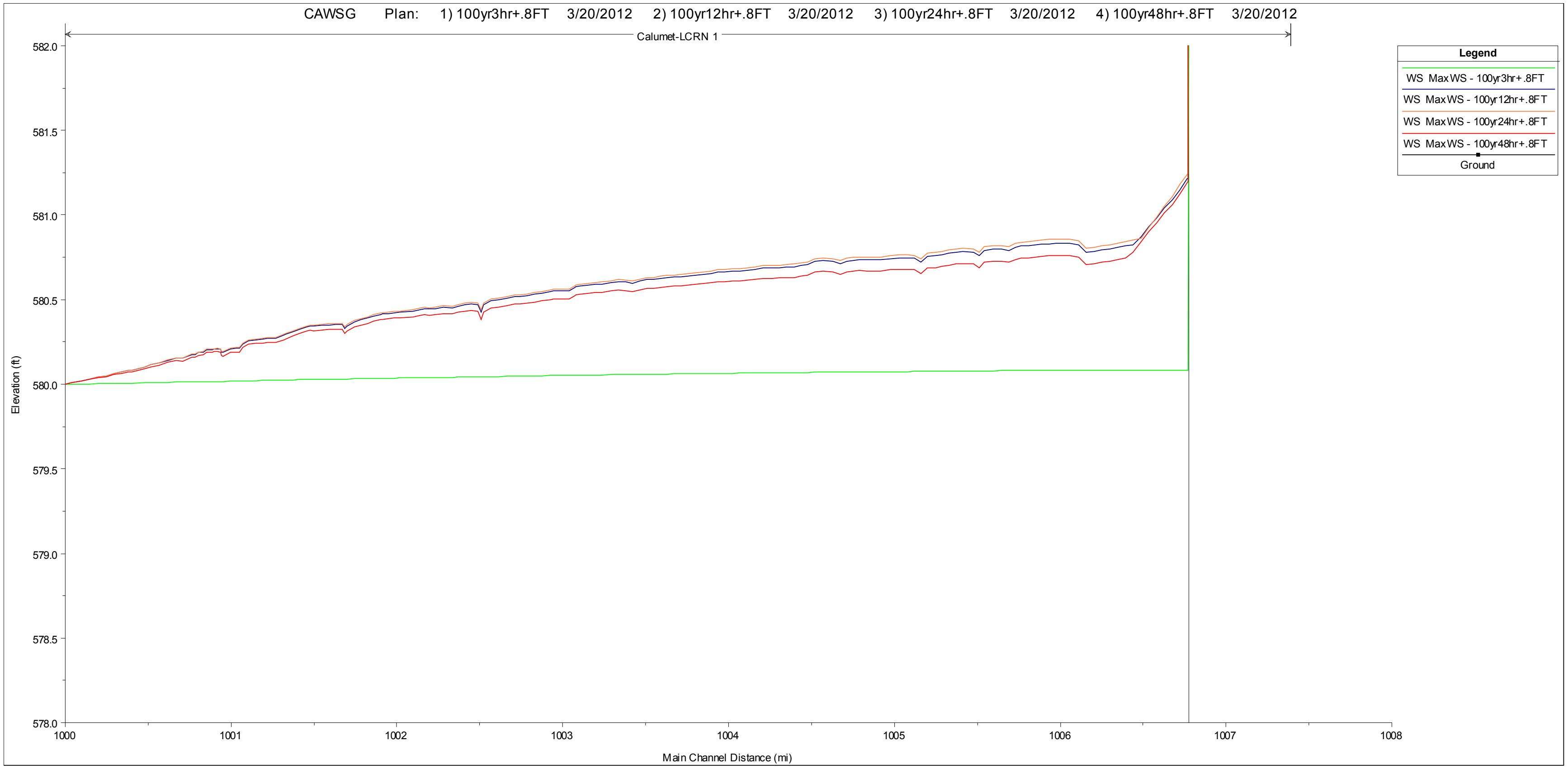

Figure 4 - Maximum water surface elevation on Calumet River upstream of O’Brien Lock and Dam (Future)
24 hr critical

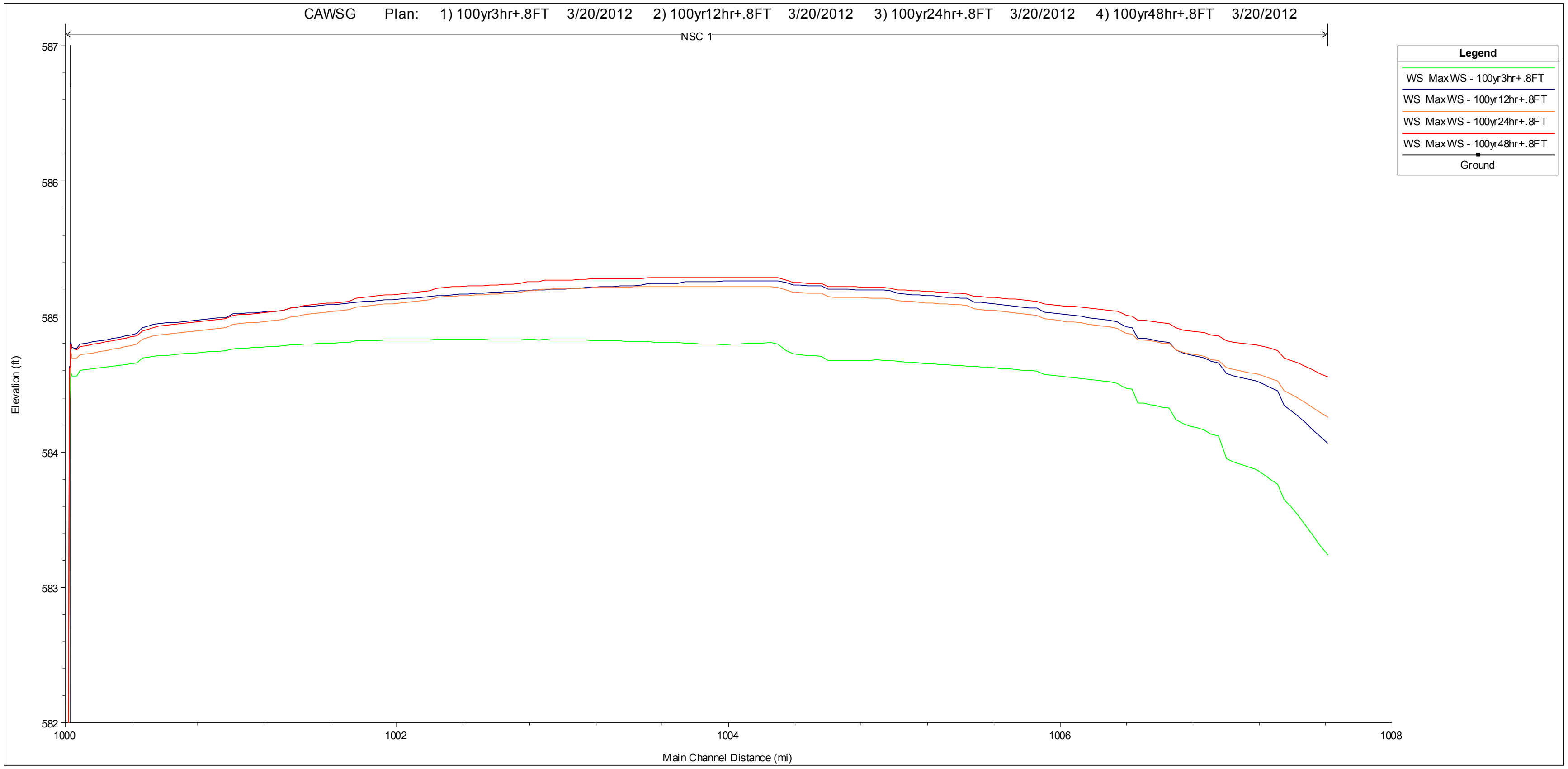

Figure 5 - Maximum water surface elevation on North Shore Channel (Future)
48 hr critical

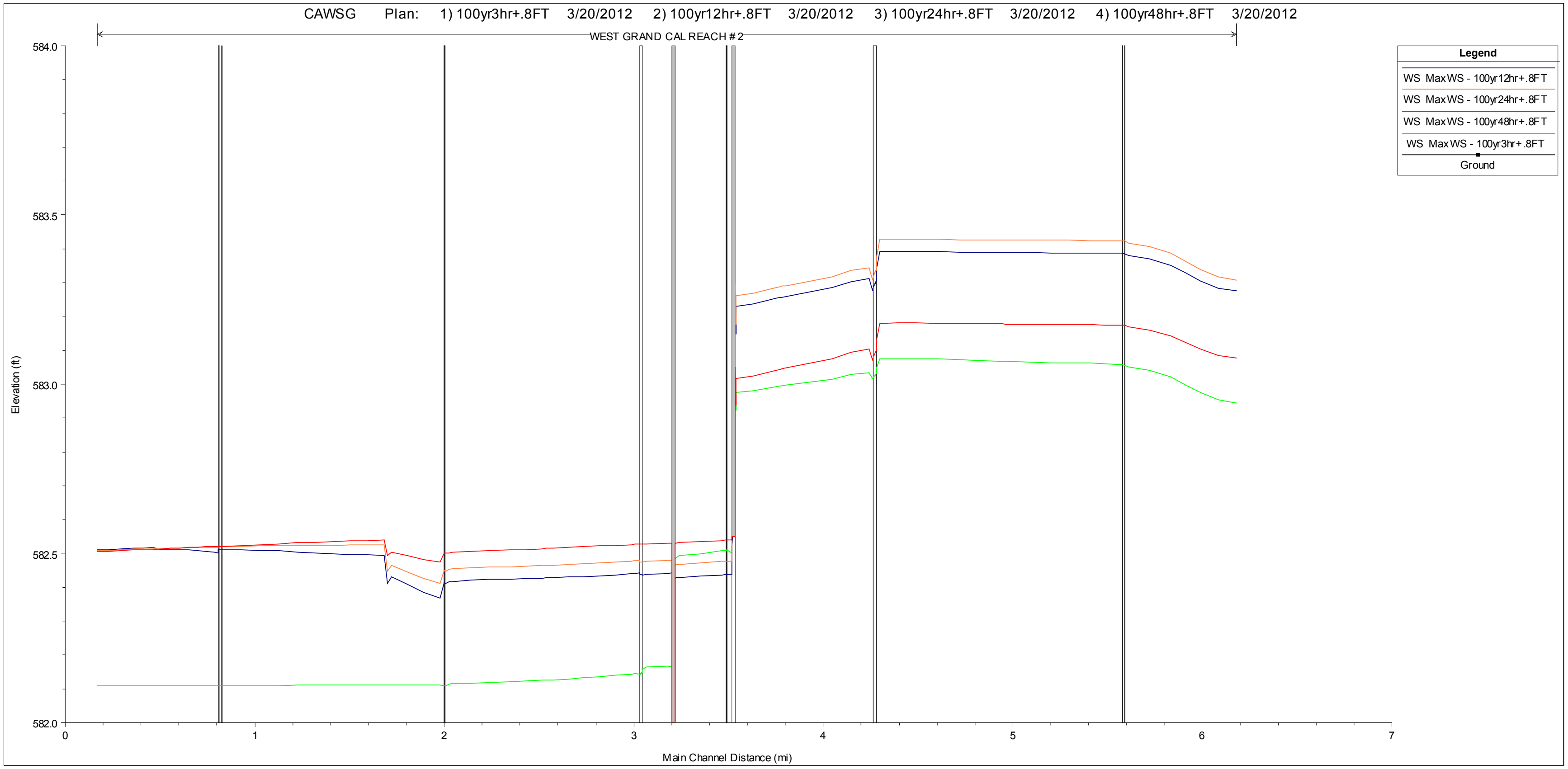

Figure 6 - Maximum water surface elevation on West Branch Grand Calumet River (Future)
24 hr critical east of Sohl Ave., 48 hr critical west of Sohl Ave.

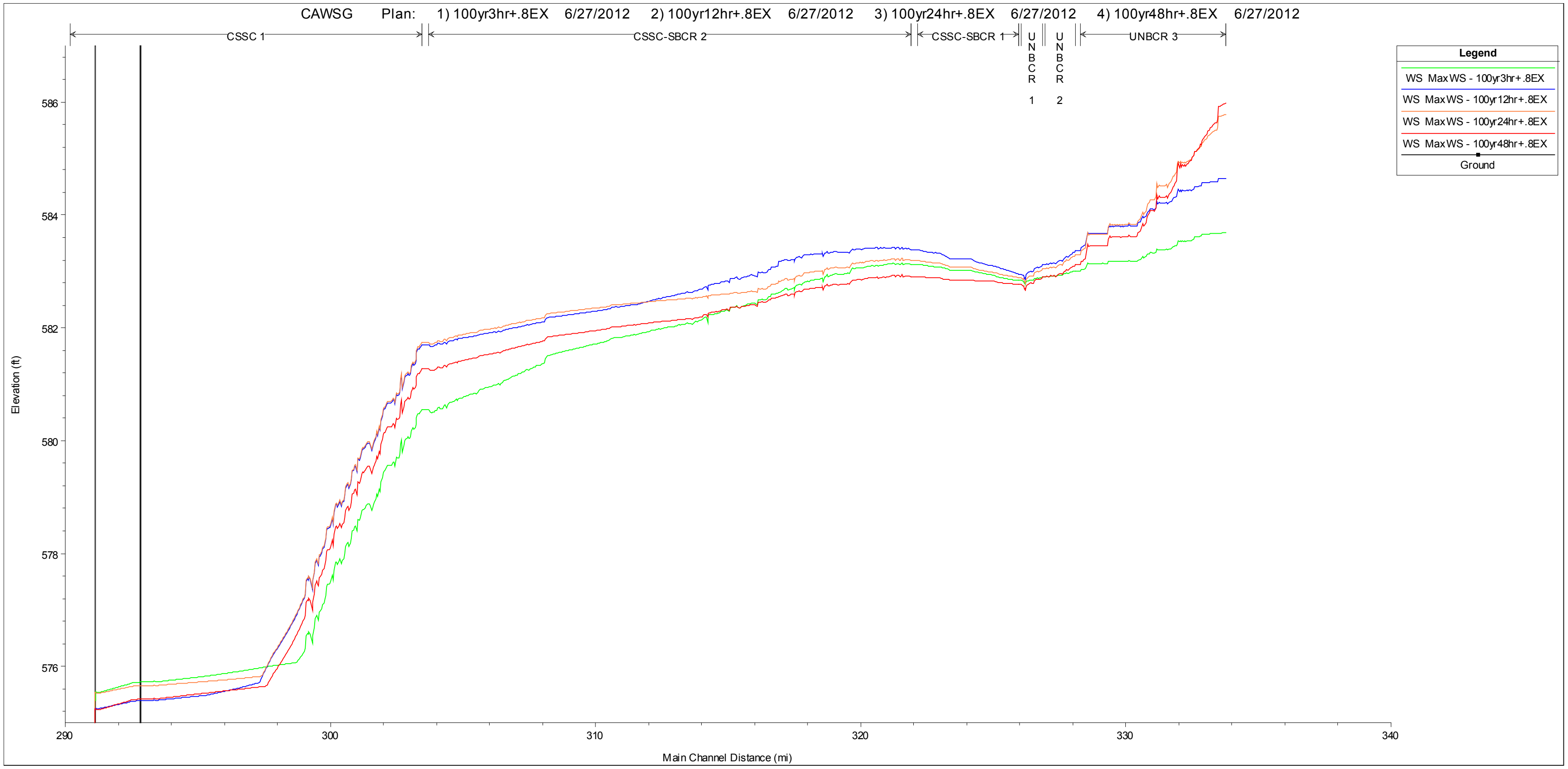

Figure 7 - Maximum water surface elevation from Lockport to NSC confluence (Existing)
24 hr critical lower CSSC, 12 hr critical upper CSSC, SBCR and lower NBCR, 48 hr critical upper NBCR

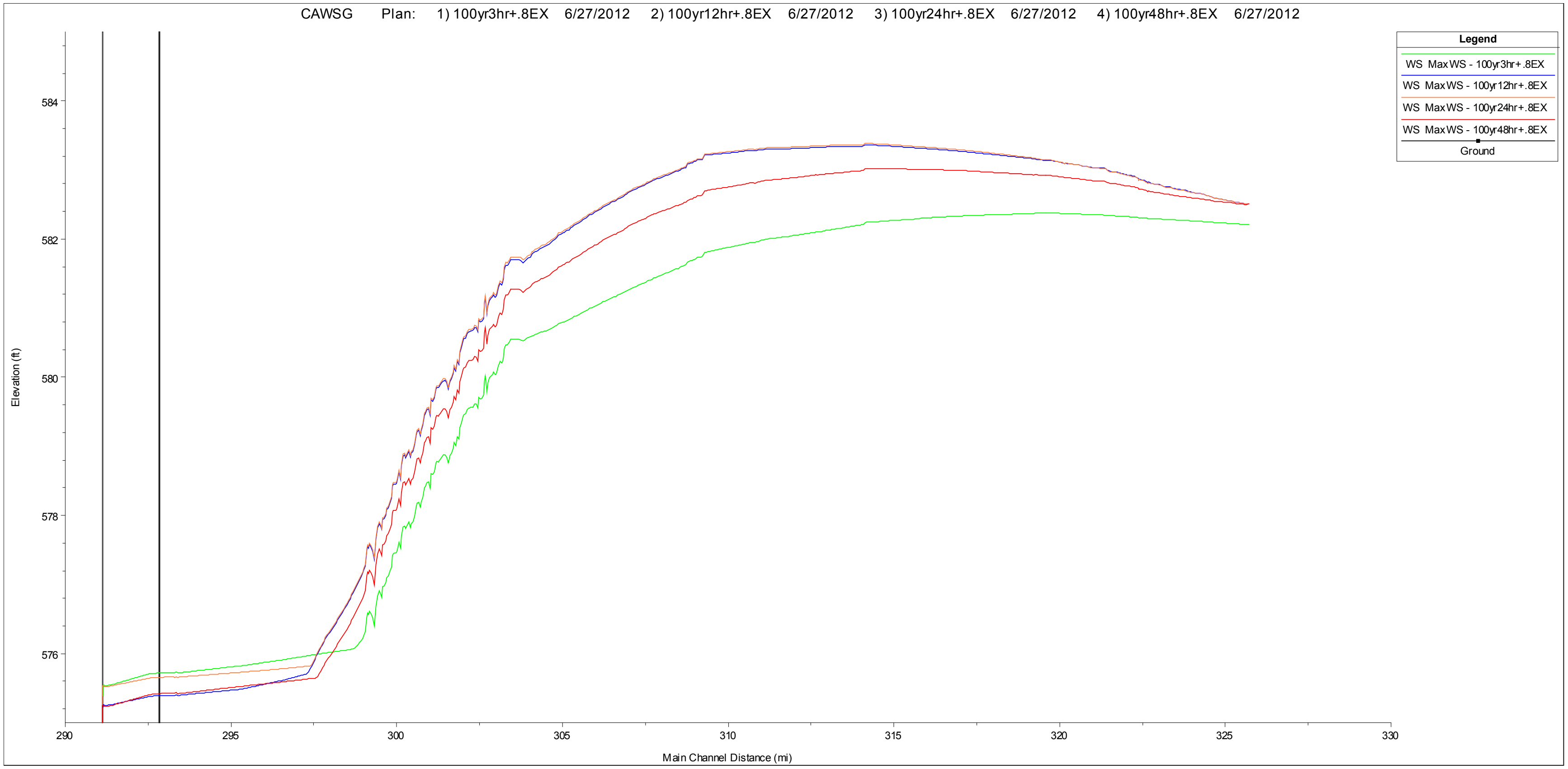

Figure 8 - Maximum water surface elevation from Lockport to O'Brien Lock and Dam (Existing)
24 hr critical

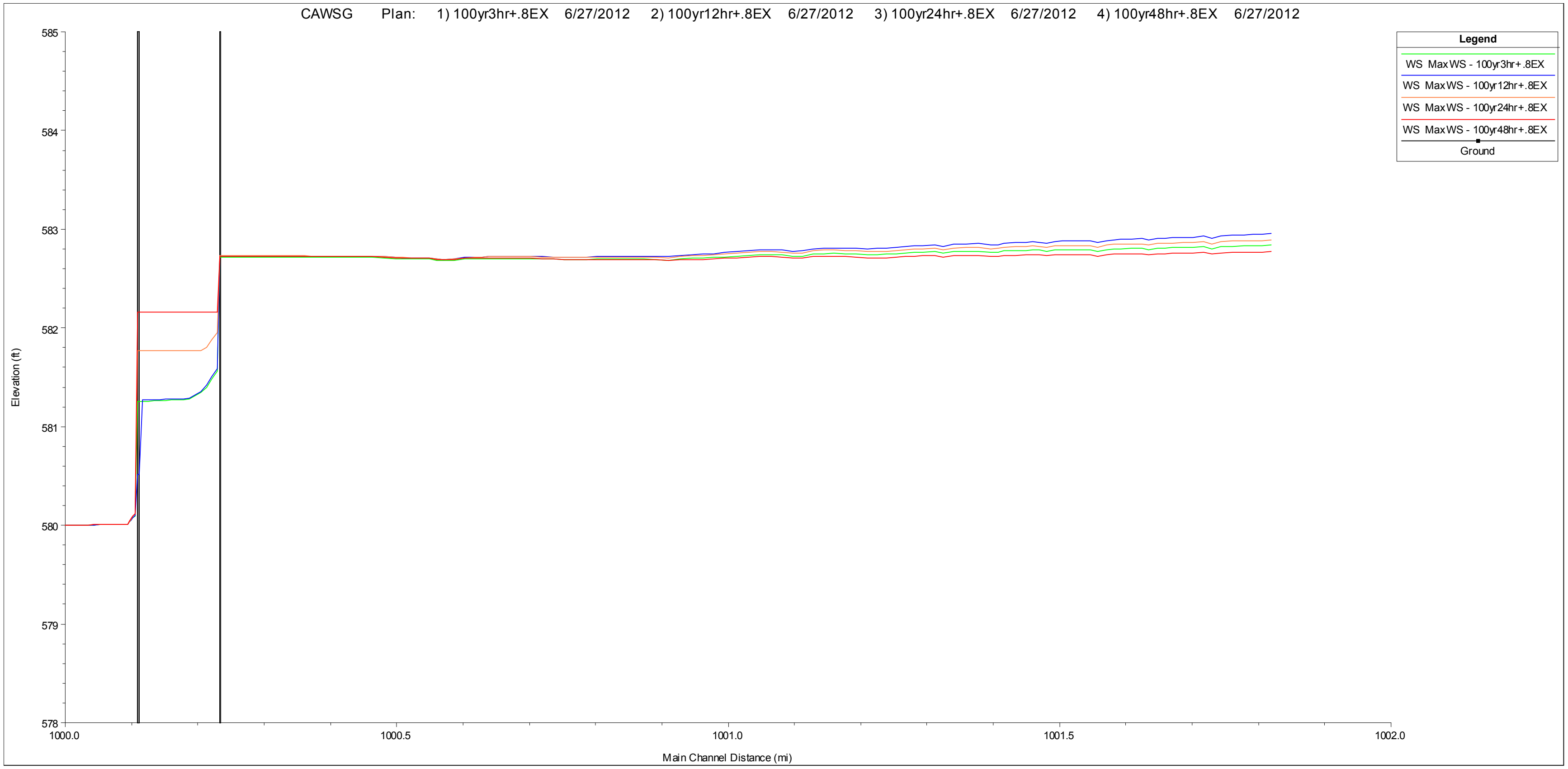

Figure 9 - Maximum water surface elevation on Chicago River (Existing)
12 hr critical

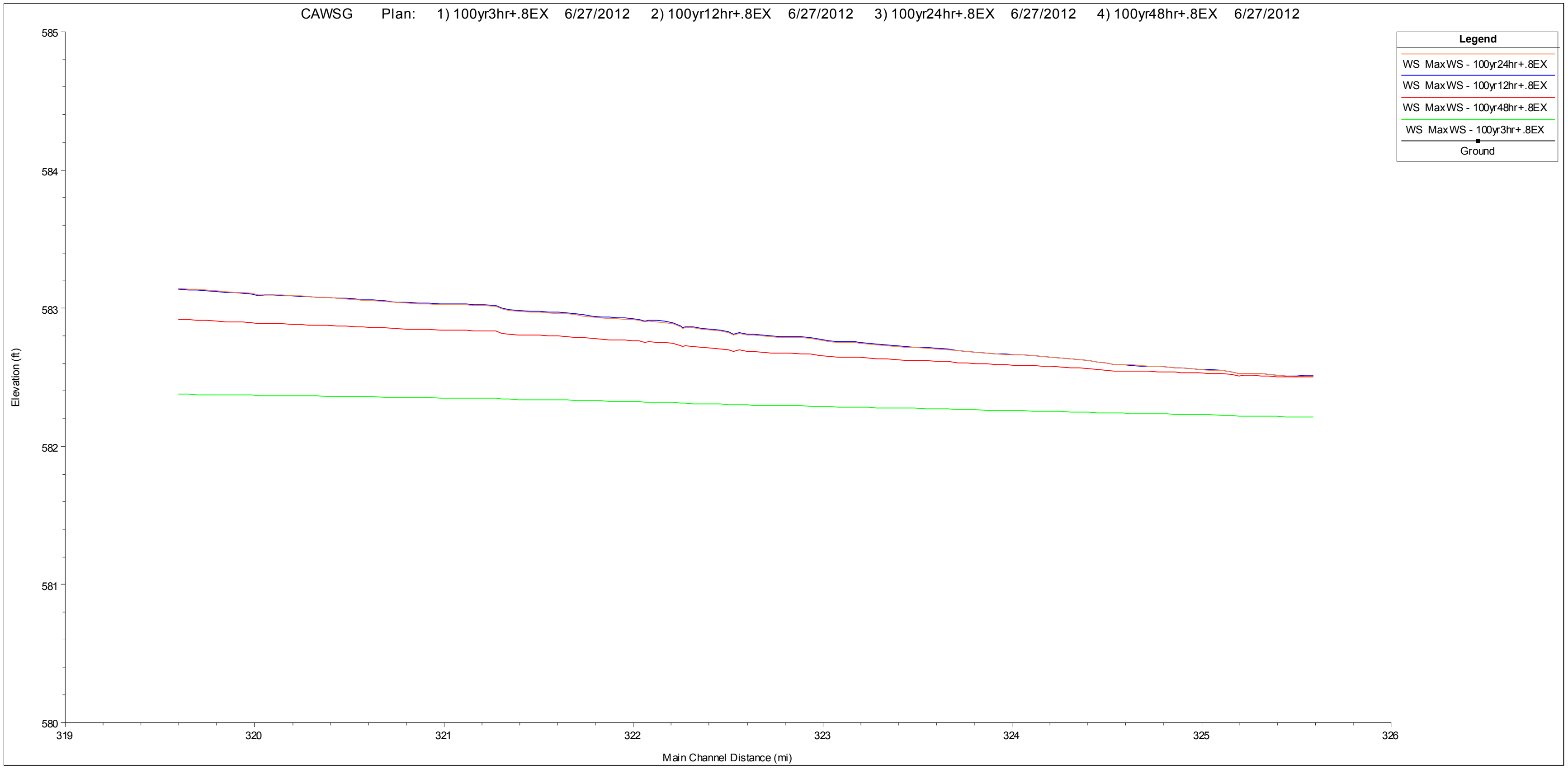

Figure 10 - Maximum water surface elevation on Calumet River upstream of O'Brien Lock and Dam (Existing)
24 hr critical

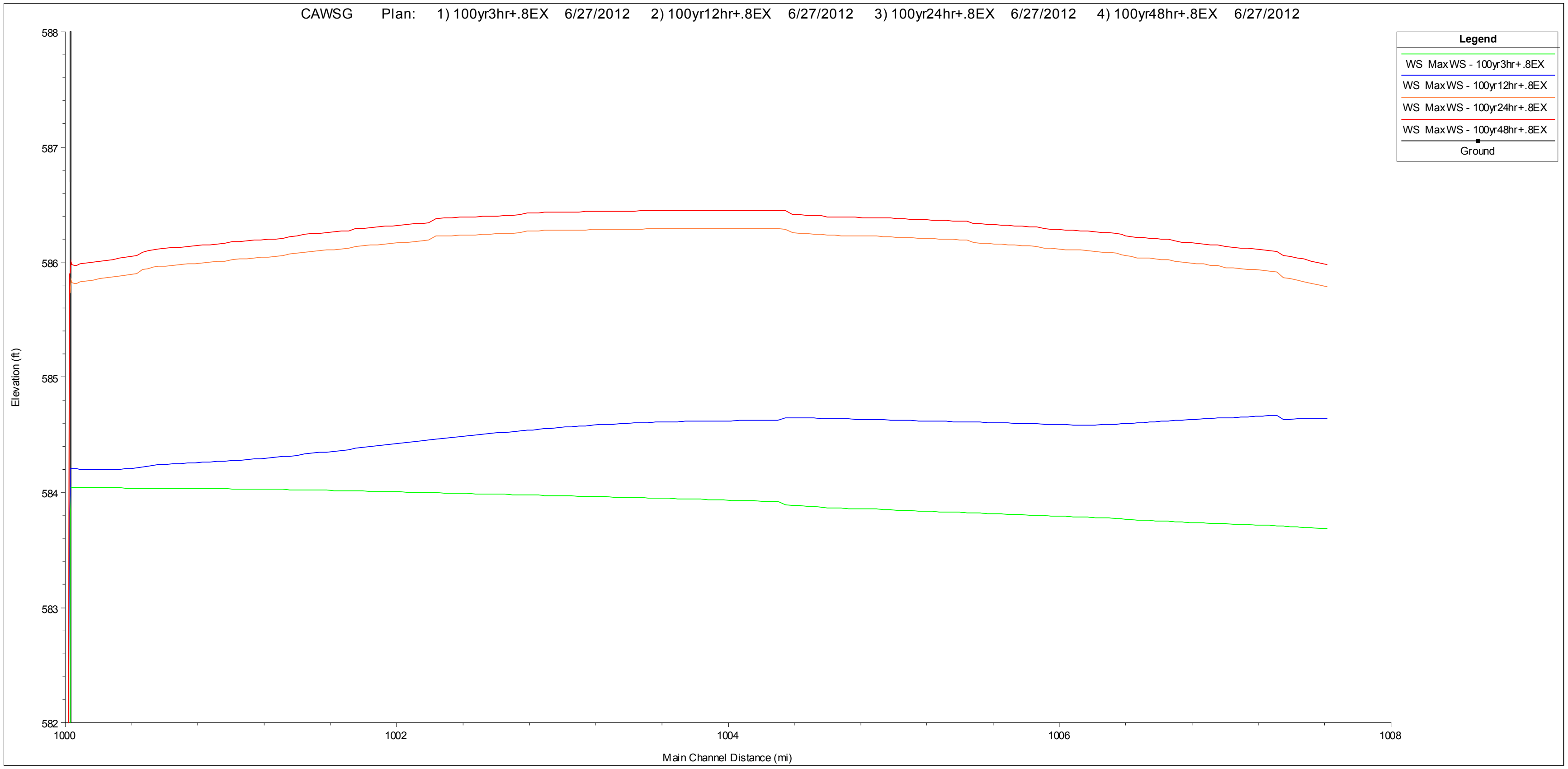

Figure 11 - Maximum water surface elevation on North Shore Channel (Existing)
48 hr critical

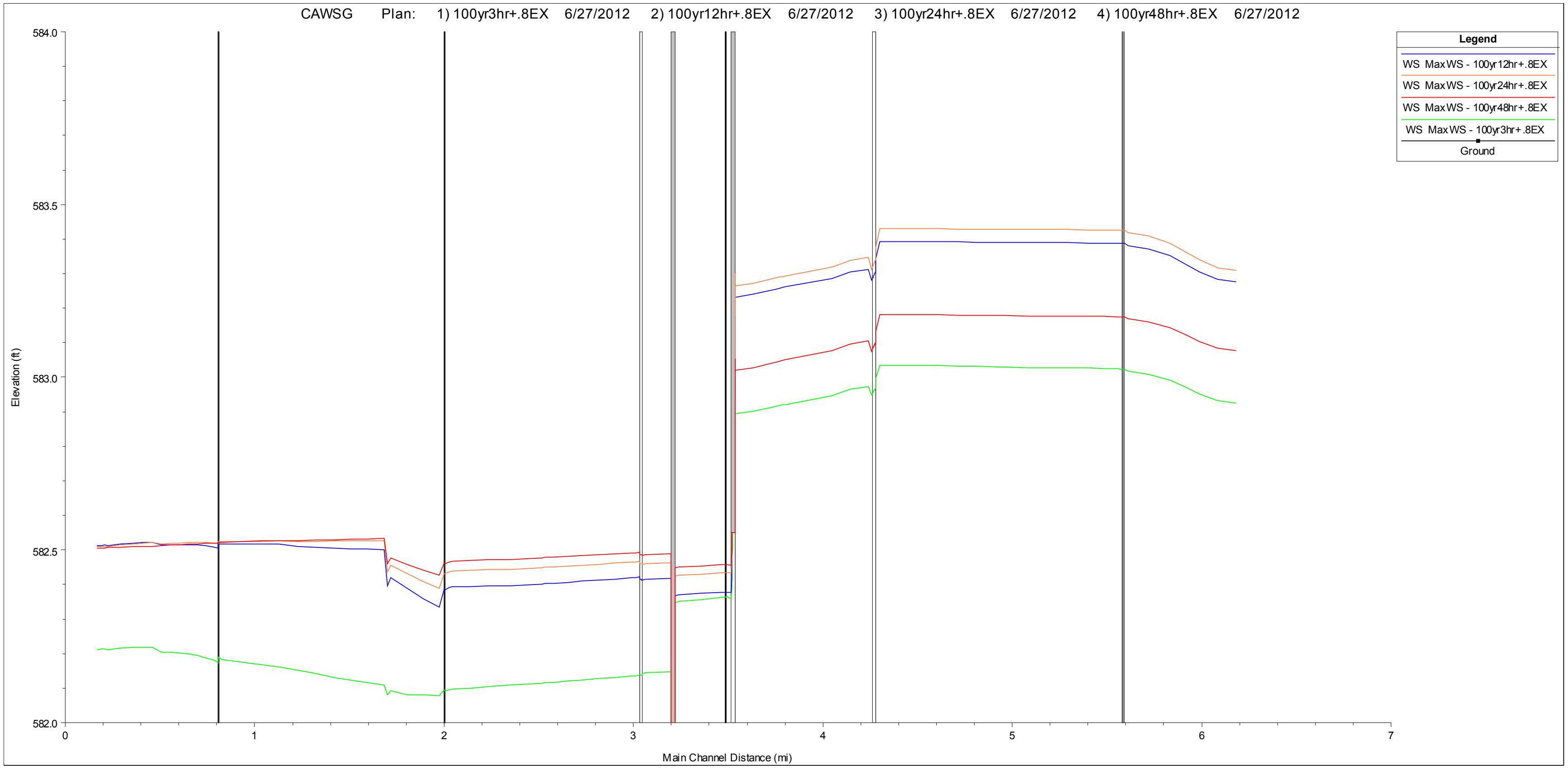

Figure 12 - Maximum water surface elevation on West Branch Grand Calumet River (Existing)
24 hr critical east of Sohl Ave., 48 hr critical west of Sohl Ave.

ENCLOSURE B

MAXIMUM WATER LEVELS ON THE CAWS

Figure 1 – Maximum Water Levels on the CSSC, SBCR and NBCR for the Baseline Condition

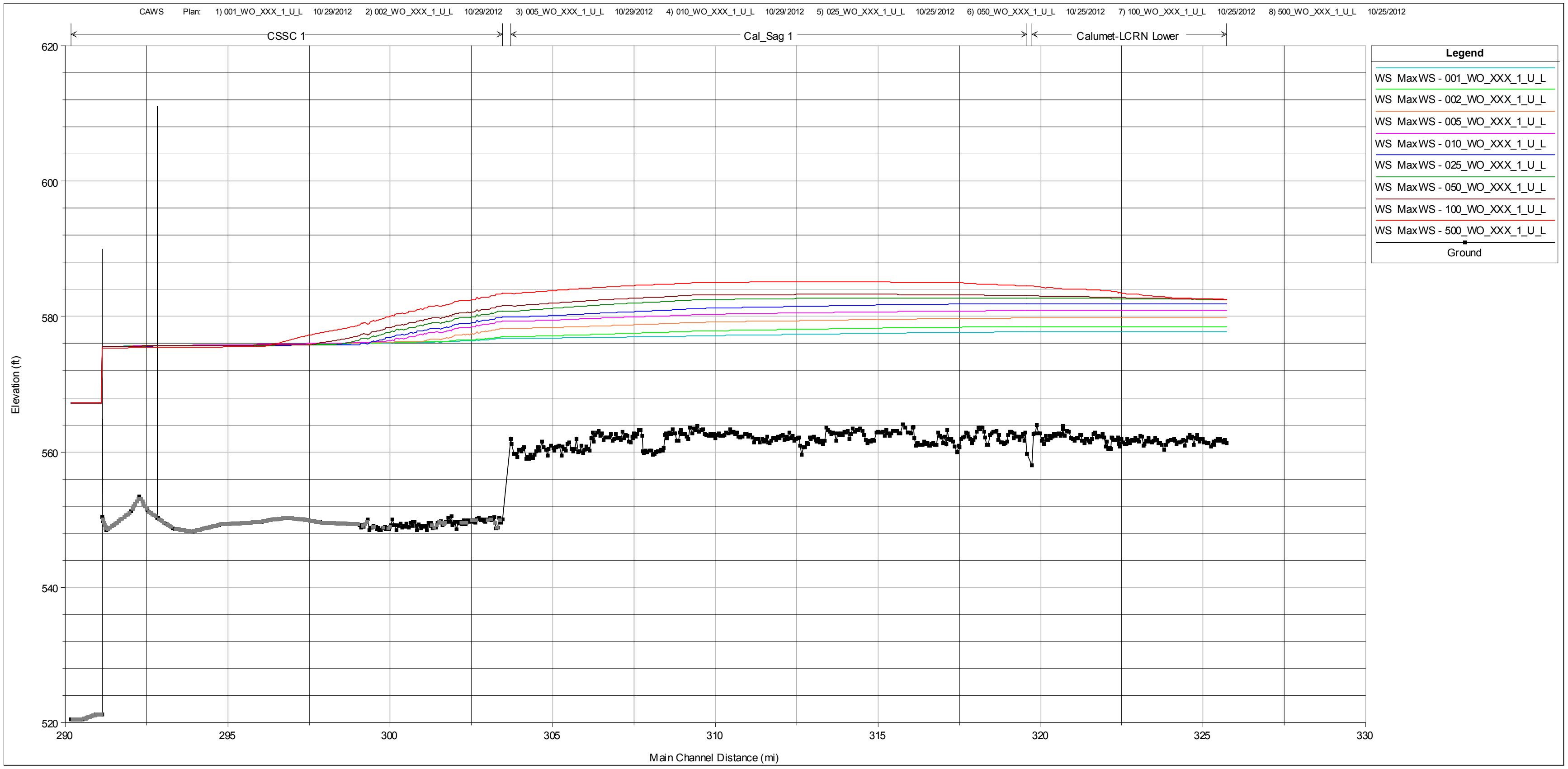

Figure 2 – Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the Baseline Condition

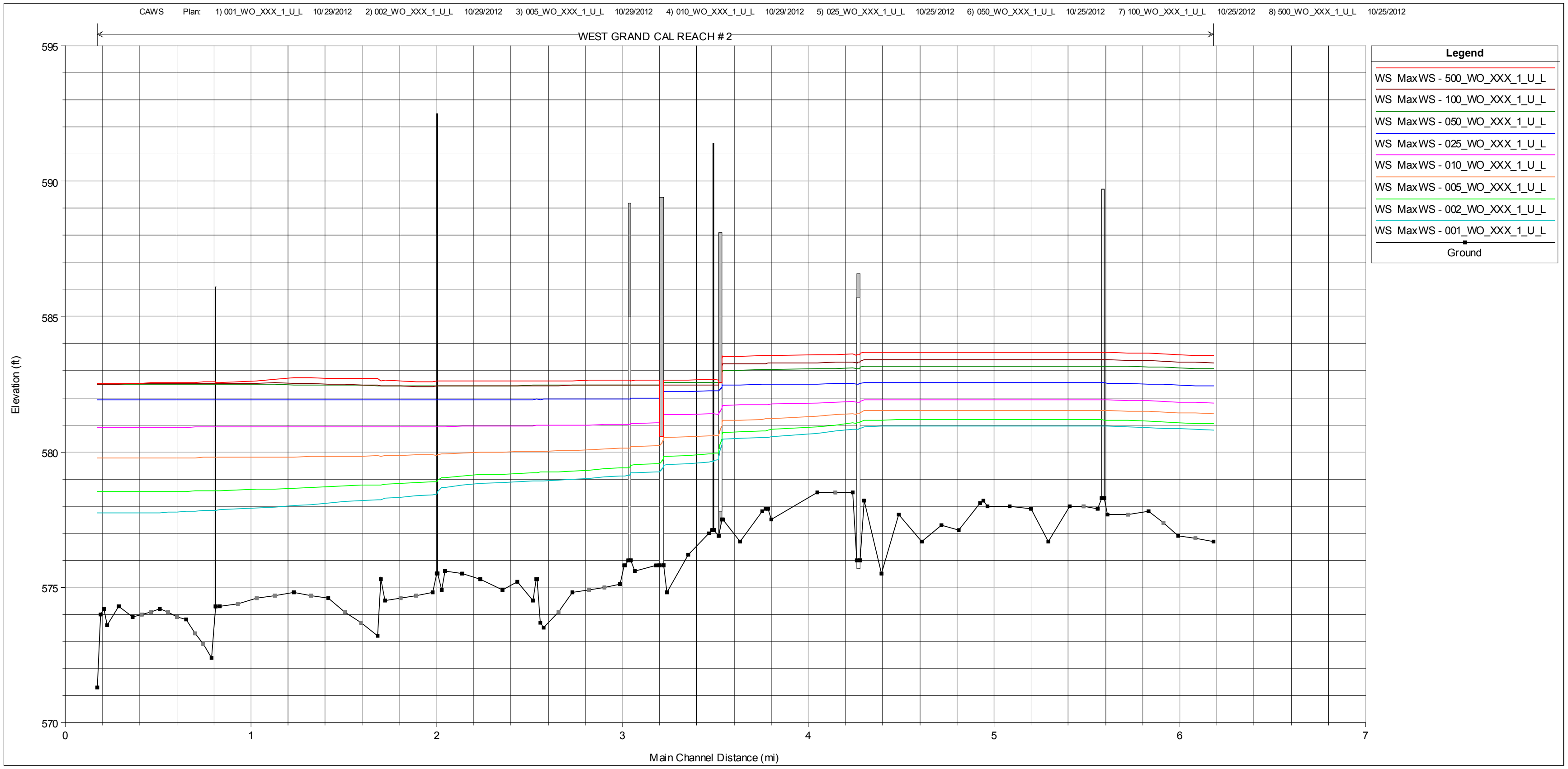

Figure 3 – Maximum Water Levels on the West Branch of Grand Calumet River for the Baseline Condition

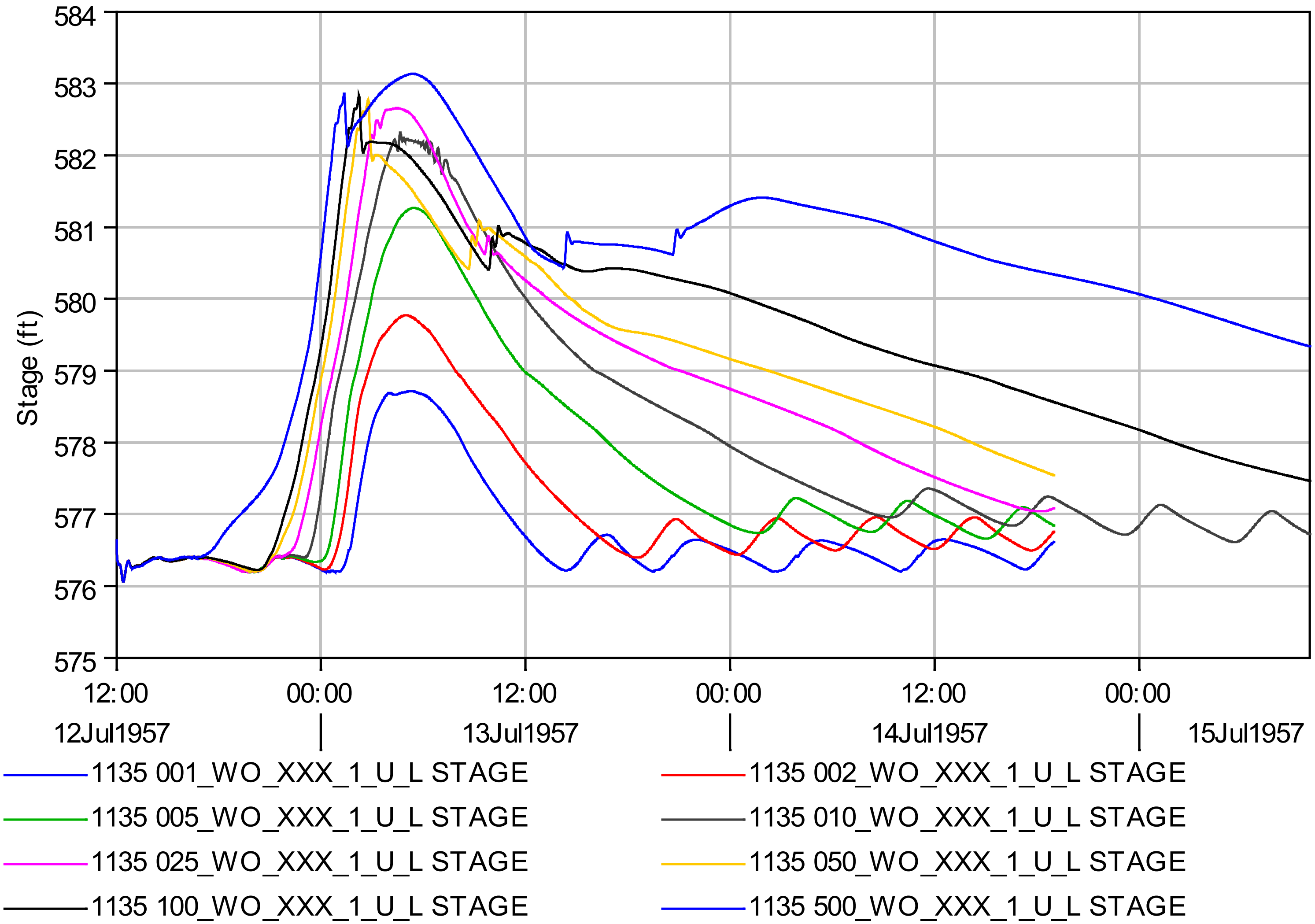

Figure 4 – Stage Hydrographs on the Chicago River near CRCW for the Baseline Condition

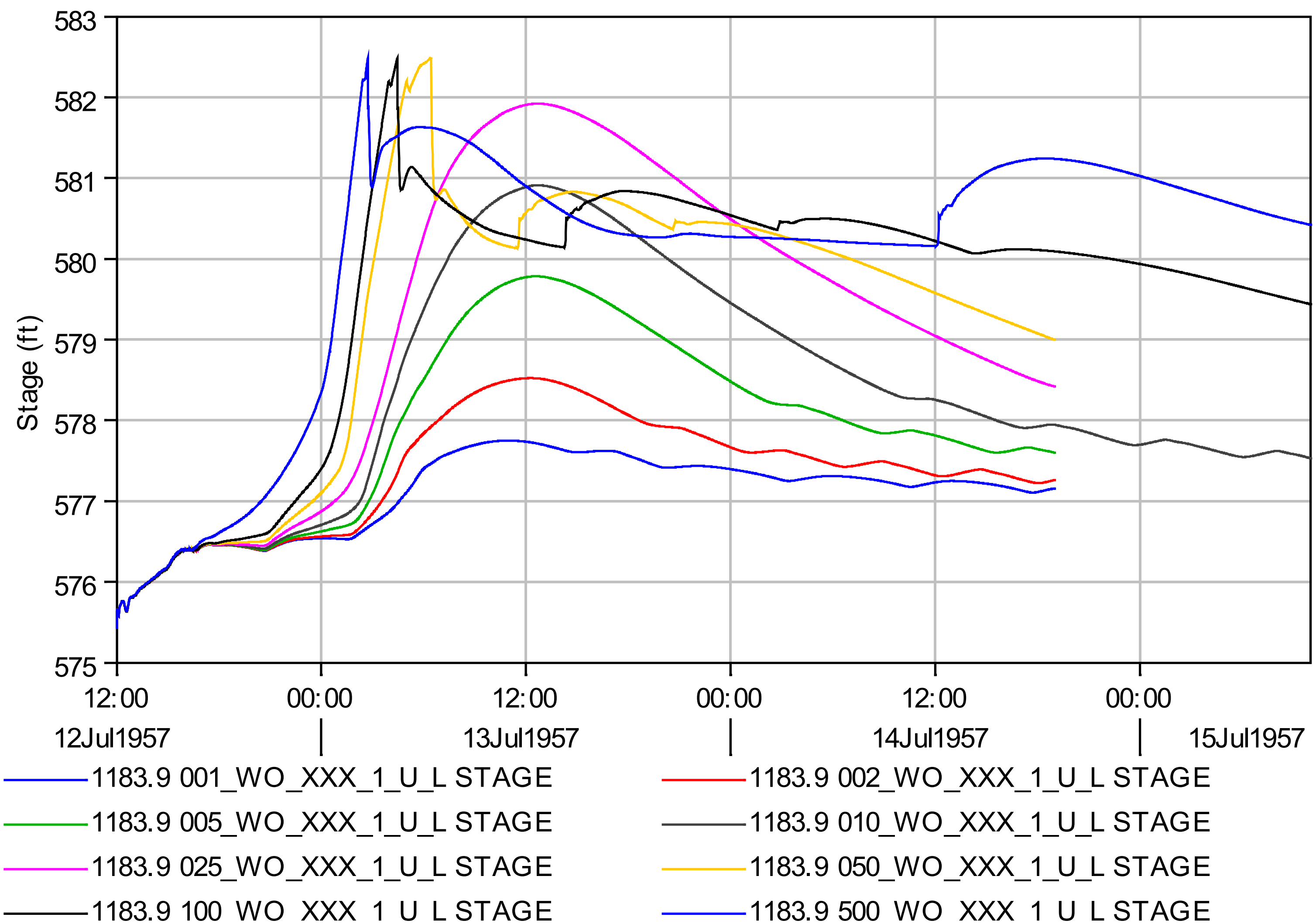

Figure 5 – Stage Hydrographs on the Calumet River near O'Brien Lock and Dam for the Baseline Condition

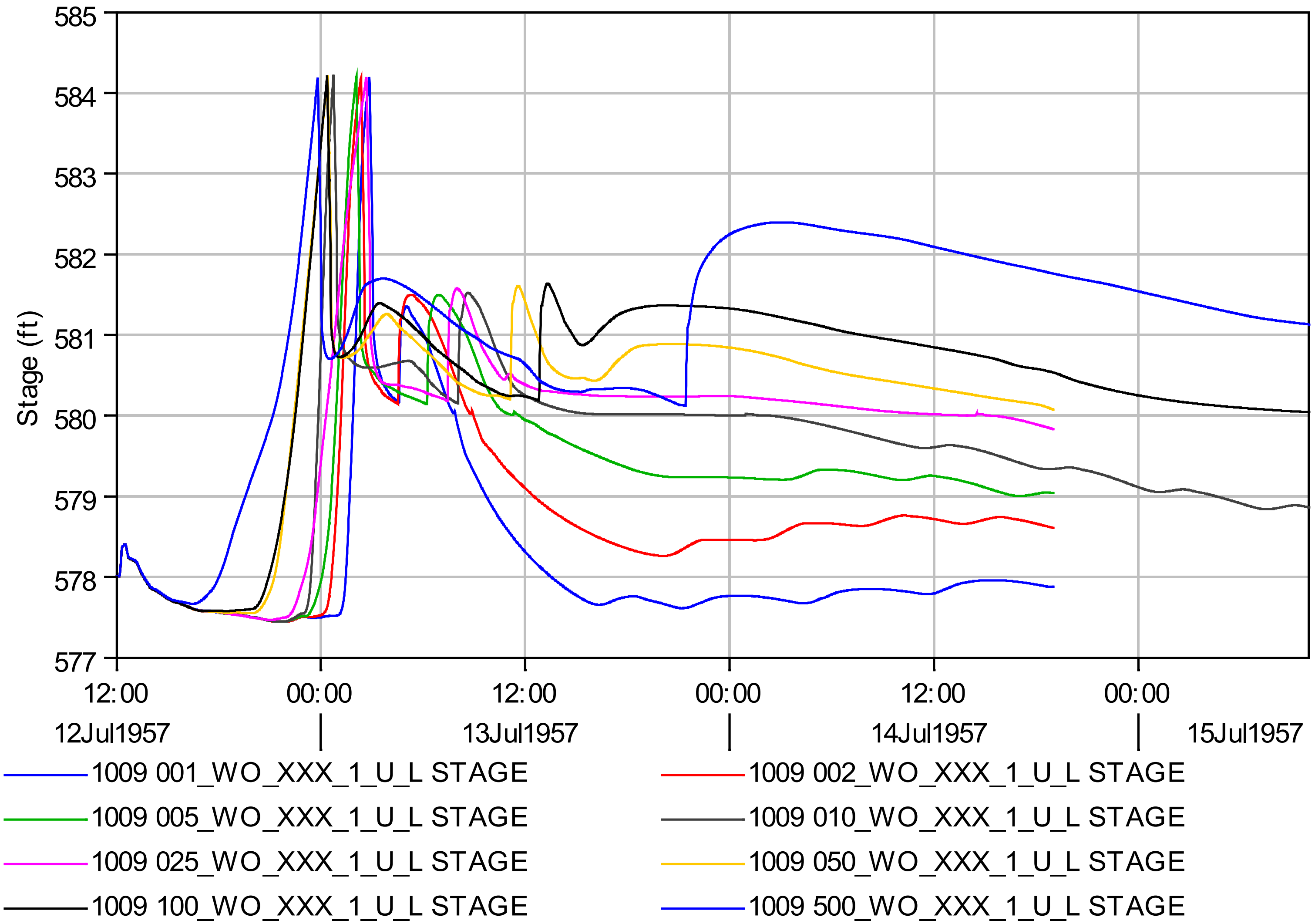

Figure 6 – Stage Hydrographs on the North Shore Channel near Wilmette Pumping Station for the Baseline Condition

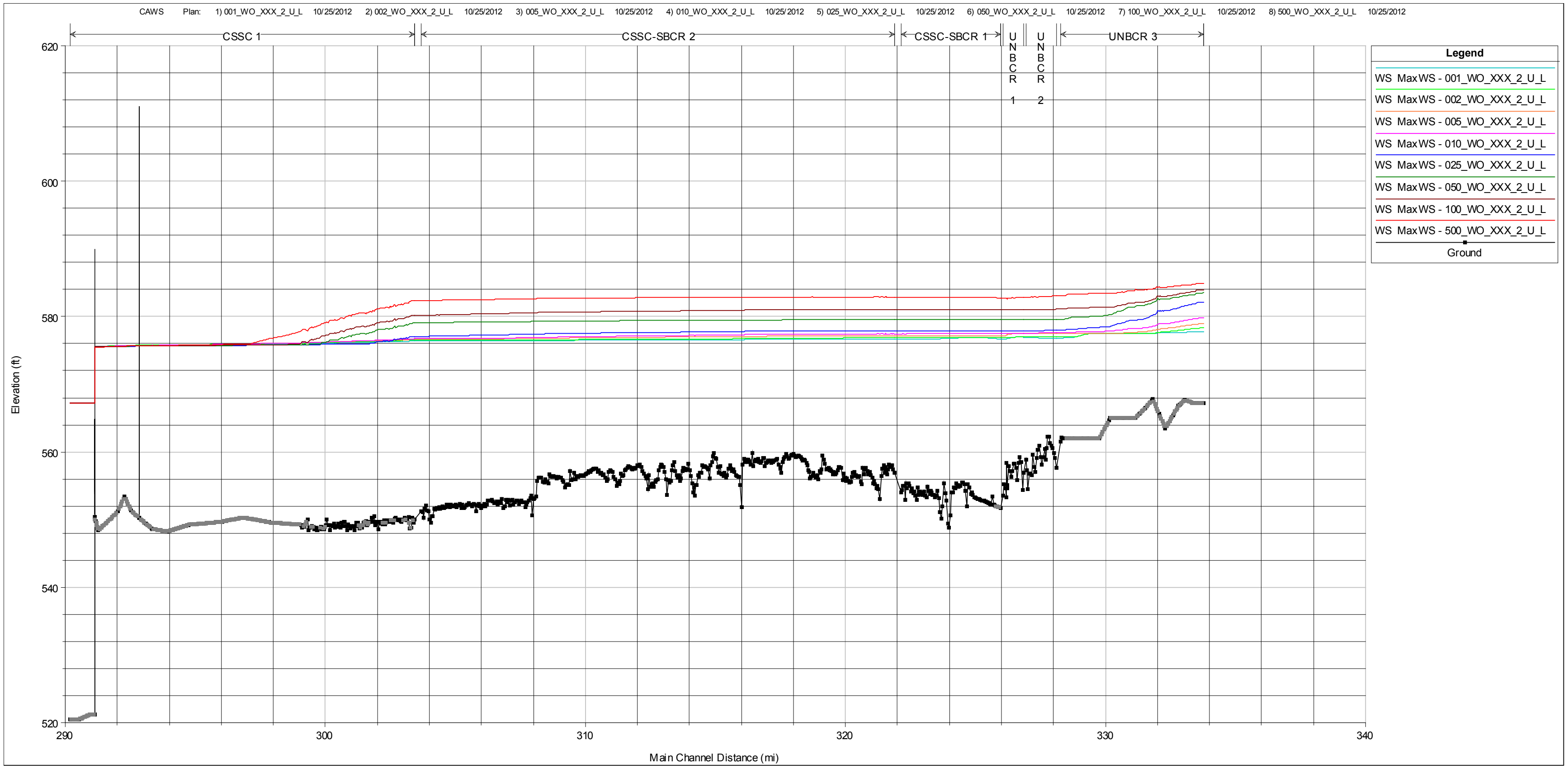

Figure 7 – Maximum Water Levels on the CSSC, SBCR and NBCR for the Future Condition

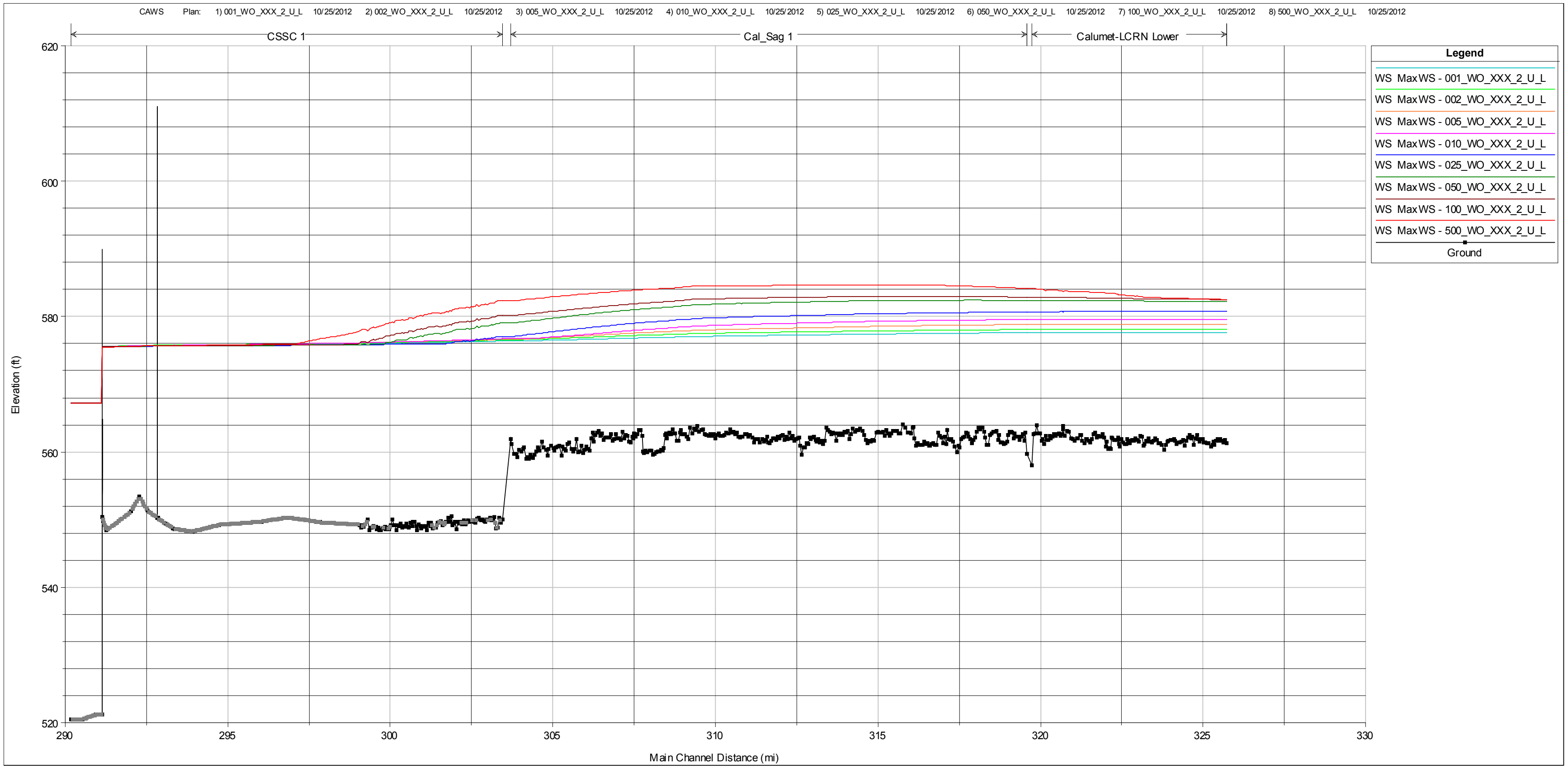

Figure 8 – Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the Future Condition

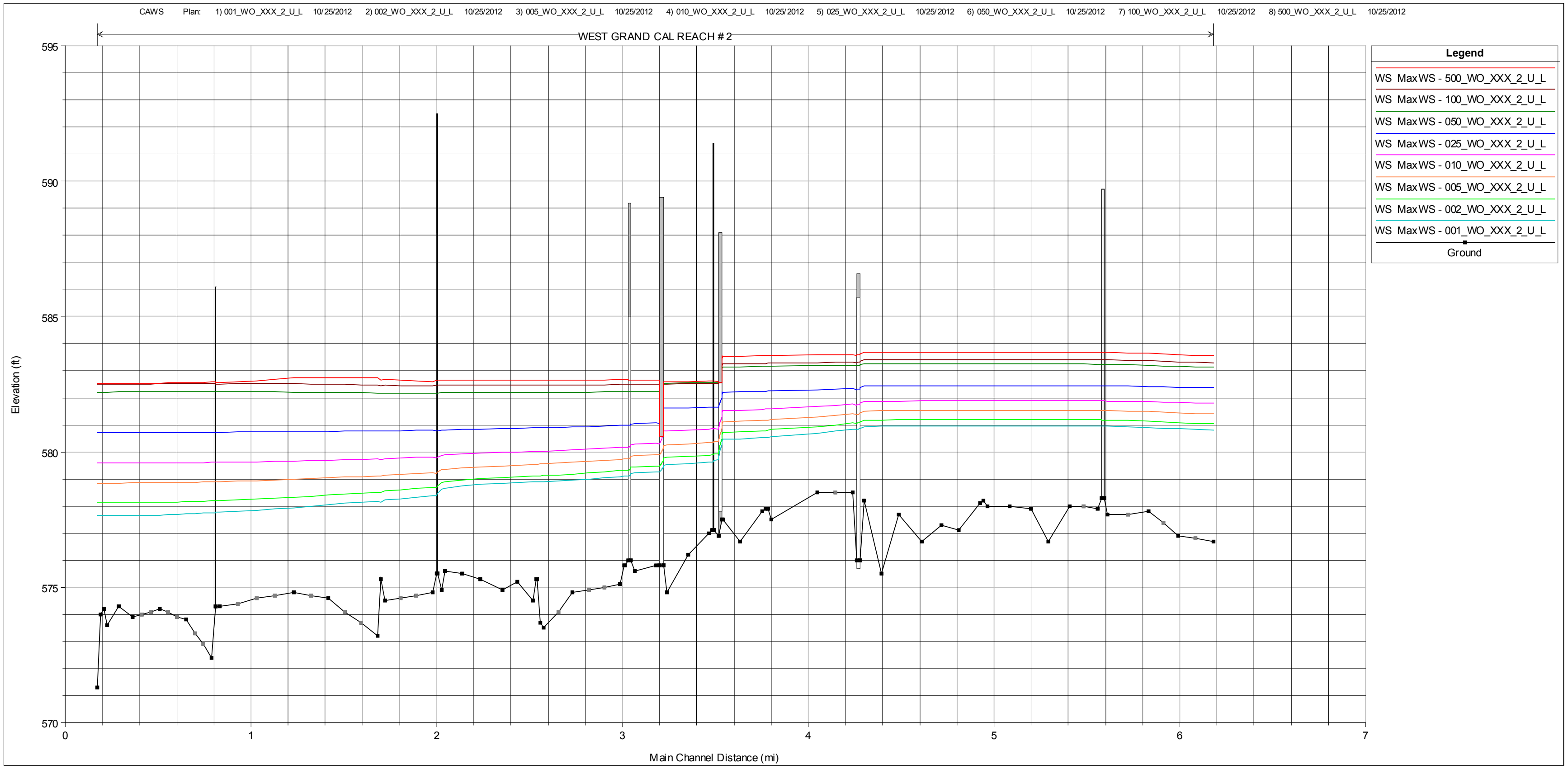

Figure 9 – Maximum Water Levels on the West Branch of Grand Calumet River for the Future Condition

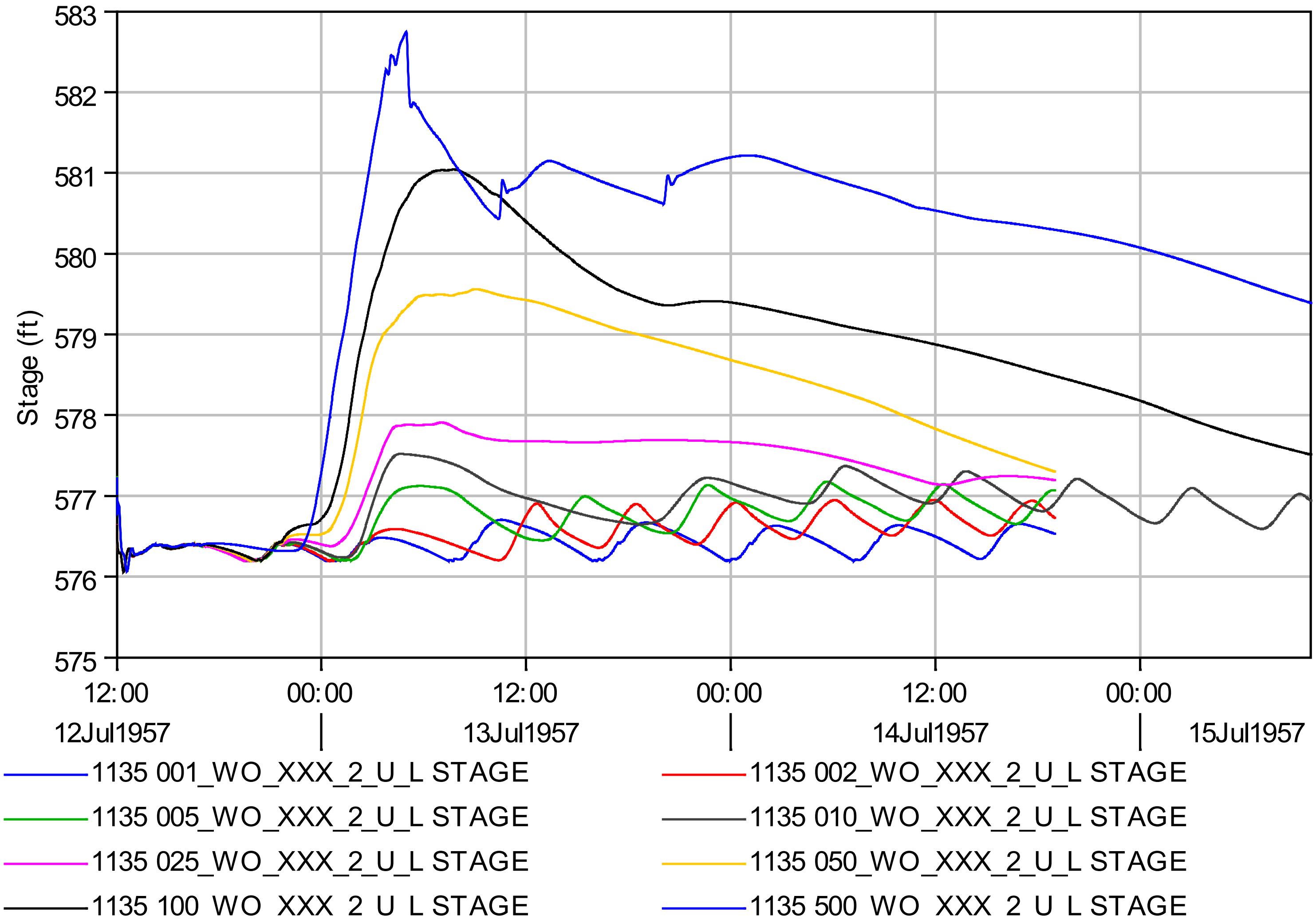

Figure 10 – Stage Hydrographs on the Chicago River near CRCW for the Future Condition

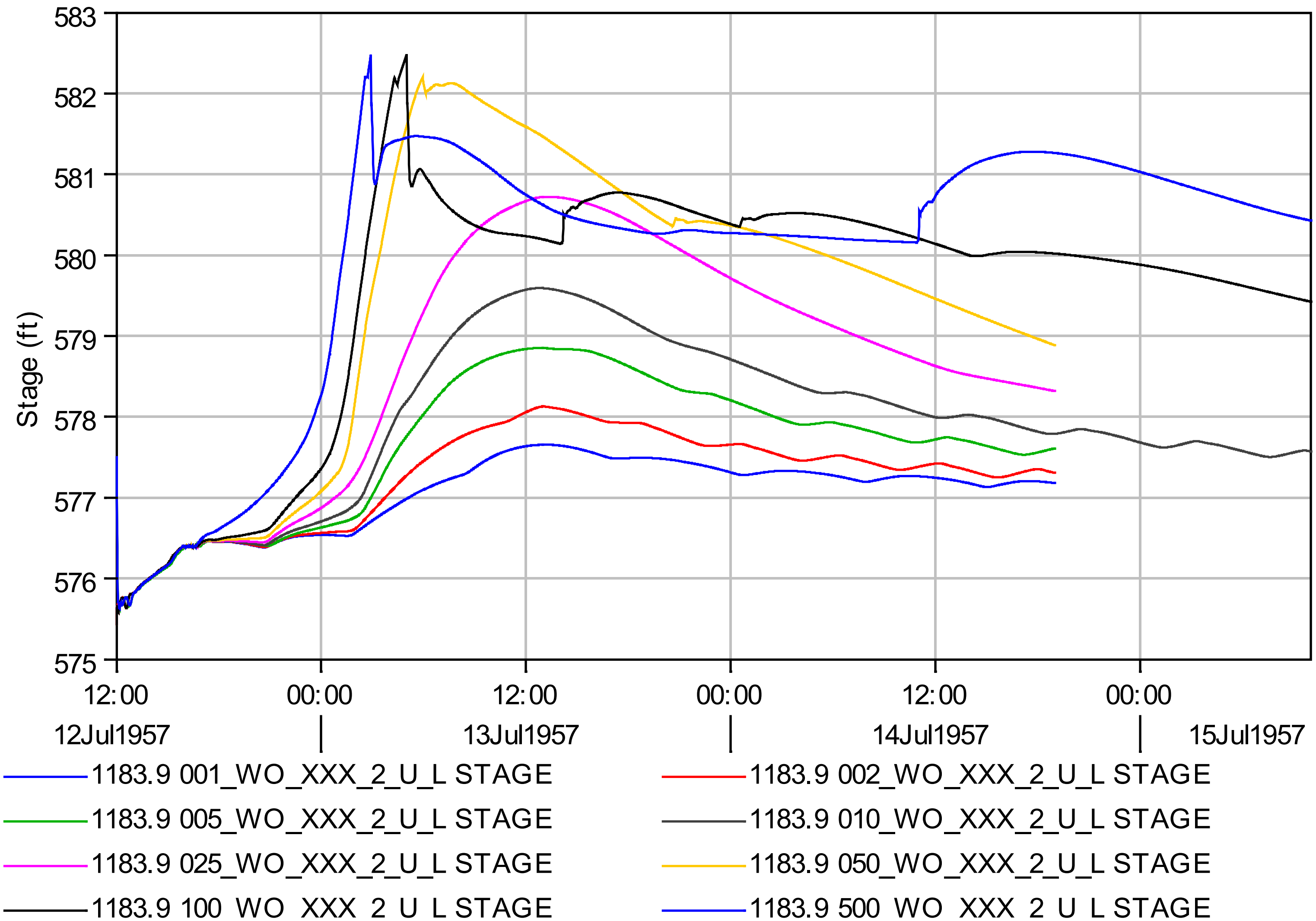

Figure 11 – Stage Hydrographs on the Calumet River near O'Brien Lock and Dam for the Future Condition

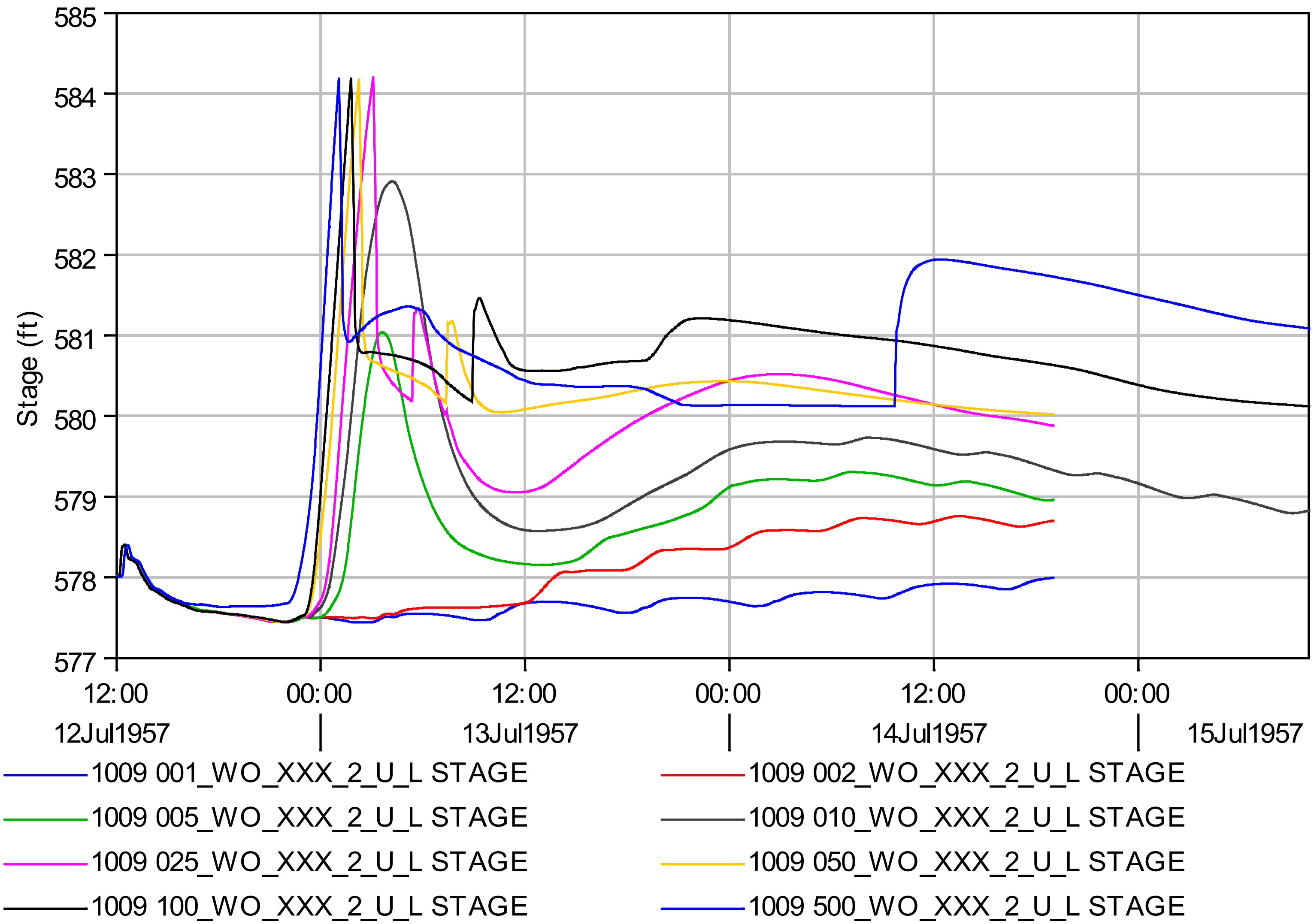

Figure 12 – Stage Hydrographs on the North Shore Channel near Wilmette Pumping Station for the Future Condition

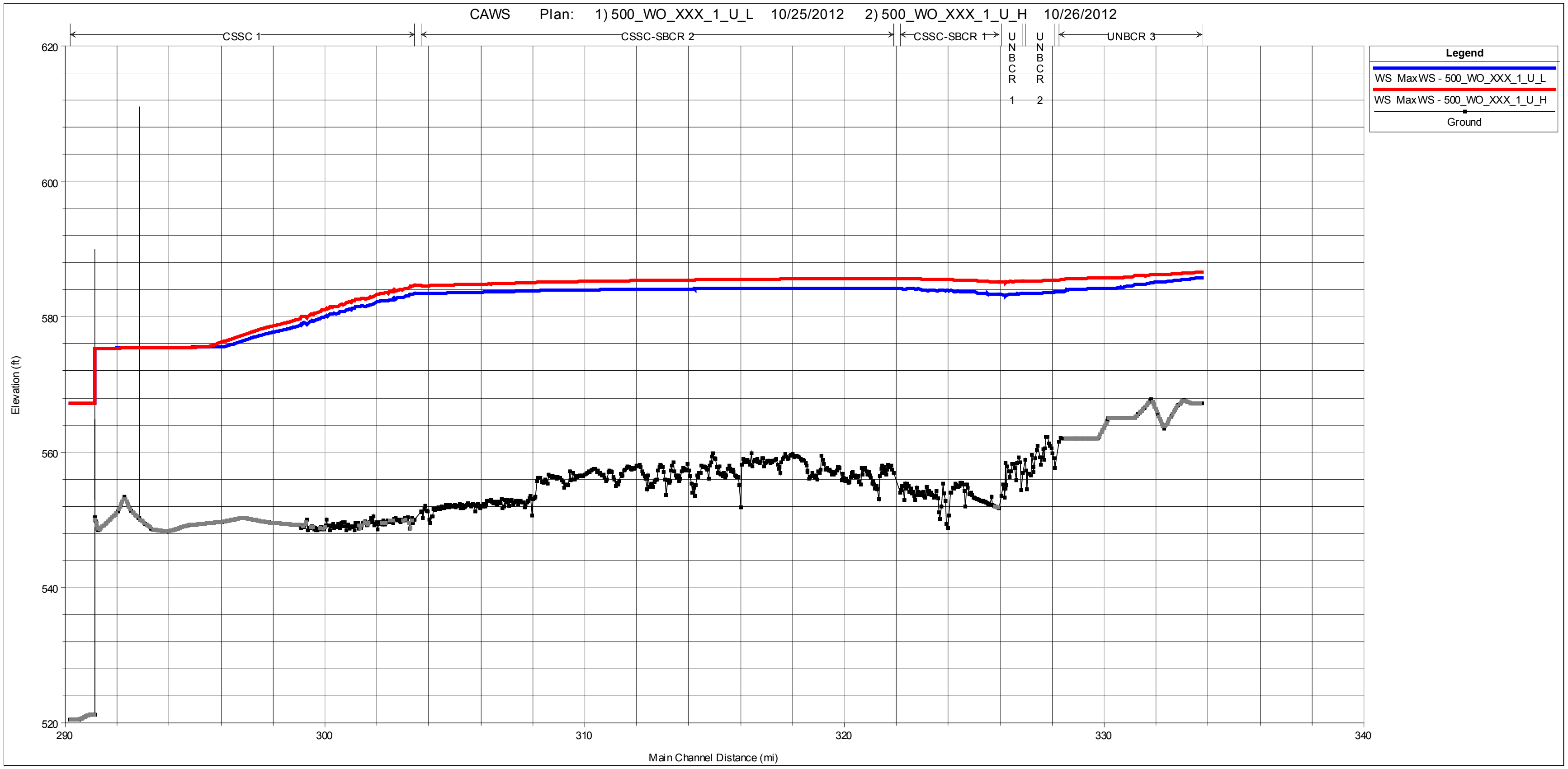

Figure 13 – Comparison of Maximum Water Levels on the CSSC, SBCR and NBCR for the 500-year Event for the Baseline Condition (Lake Level at 580 ft NAVD vs. 583 ft NAVD)

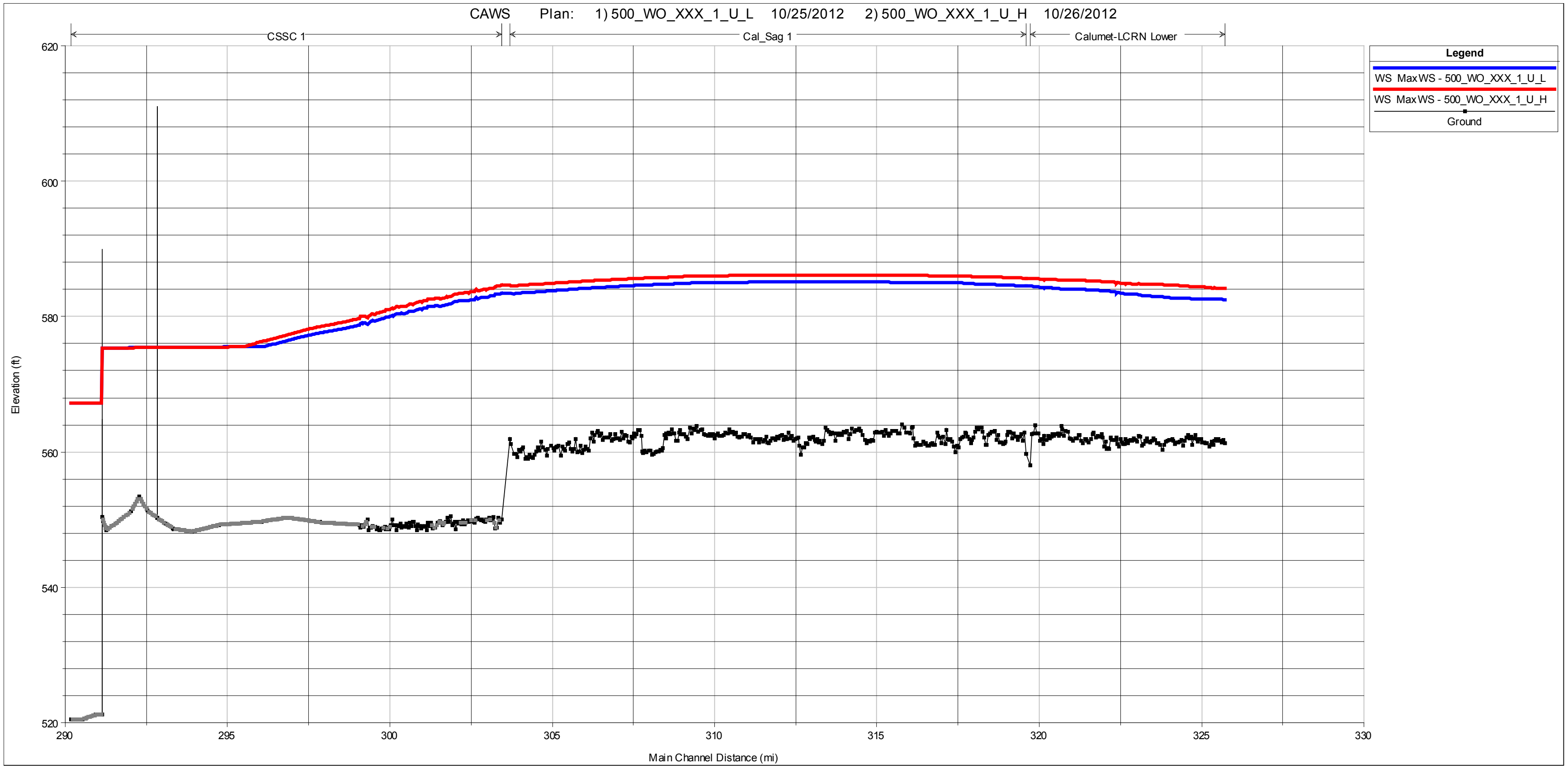

Figure 14 – Comparison of Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the 500-year Event for the Baseline Condition (Lake Level at 580 ft NAVD vs. 583 ft NAVD)

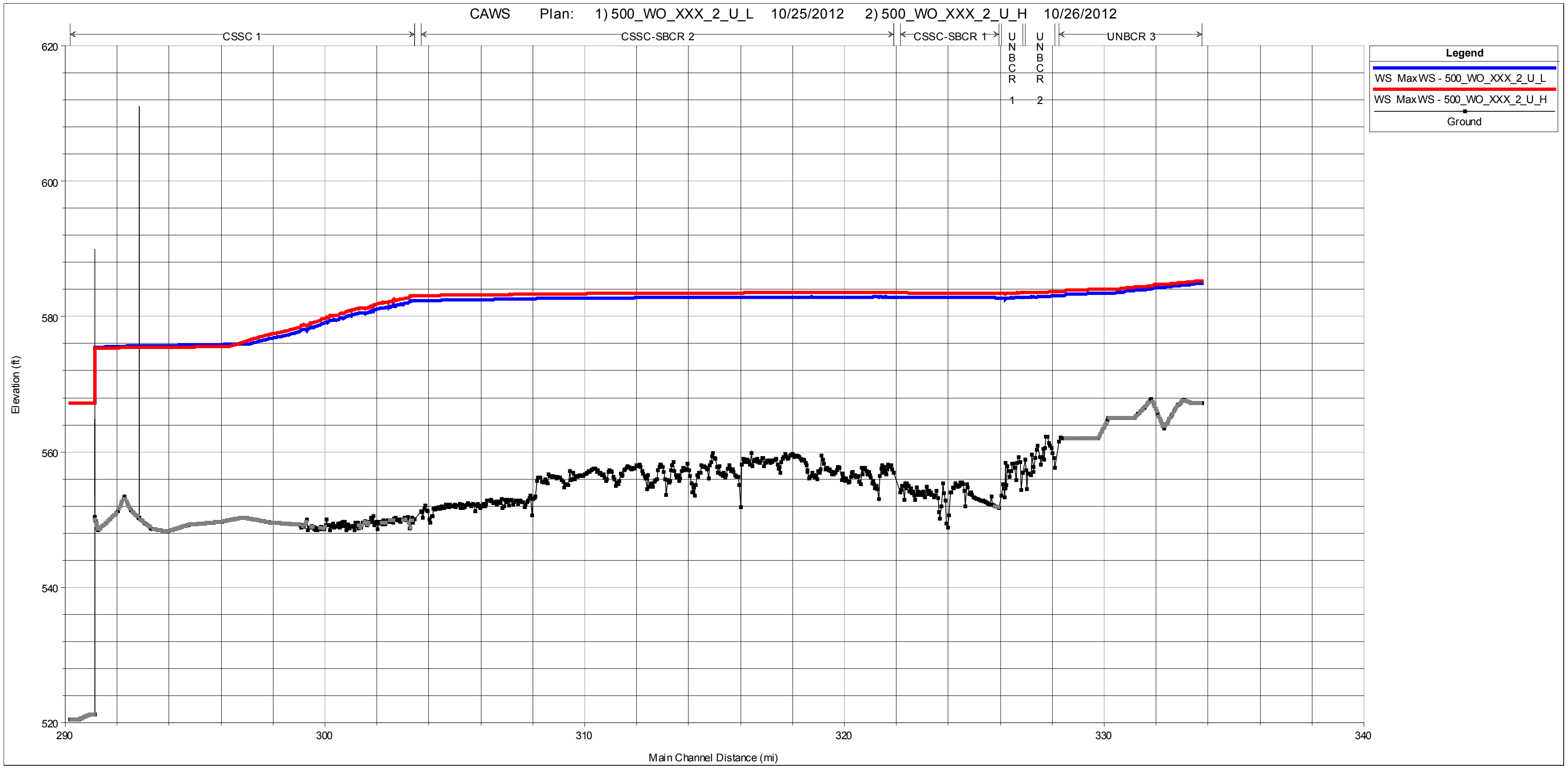

Figure 15 – Comparison of Maximum Water Levels on the CSSC, SBCR and NBCR for the 500-year Event for the Future Condition (Lake Level at 580 ft NAVD vs. 583 ft NAVD)

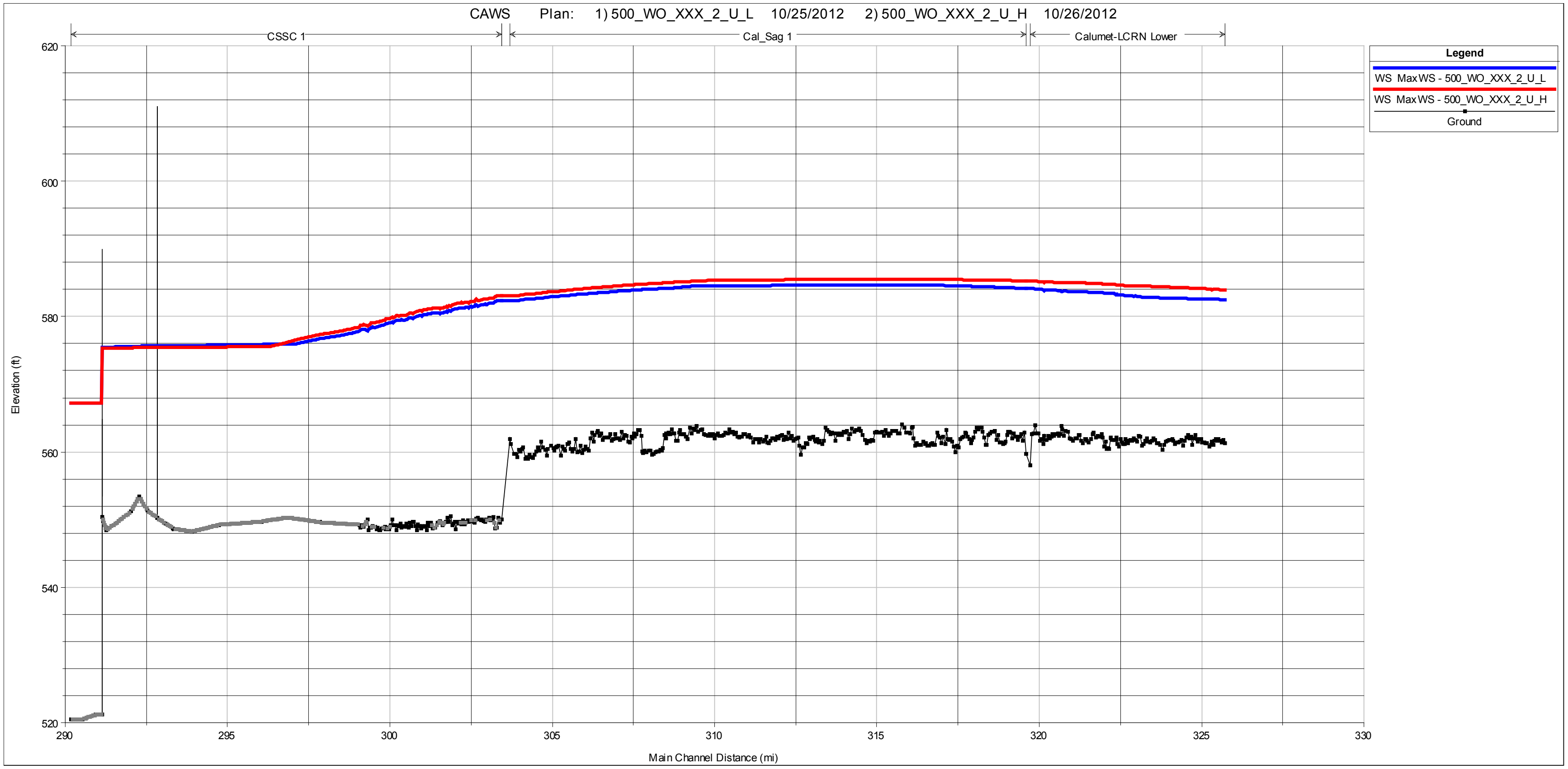

Figure 16 – Comparison of Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the 500-year Event for the Future Condition (Lake Level at 580 ft NAVD vs. 583 ft NAVD)

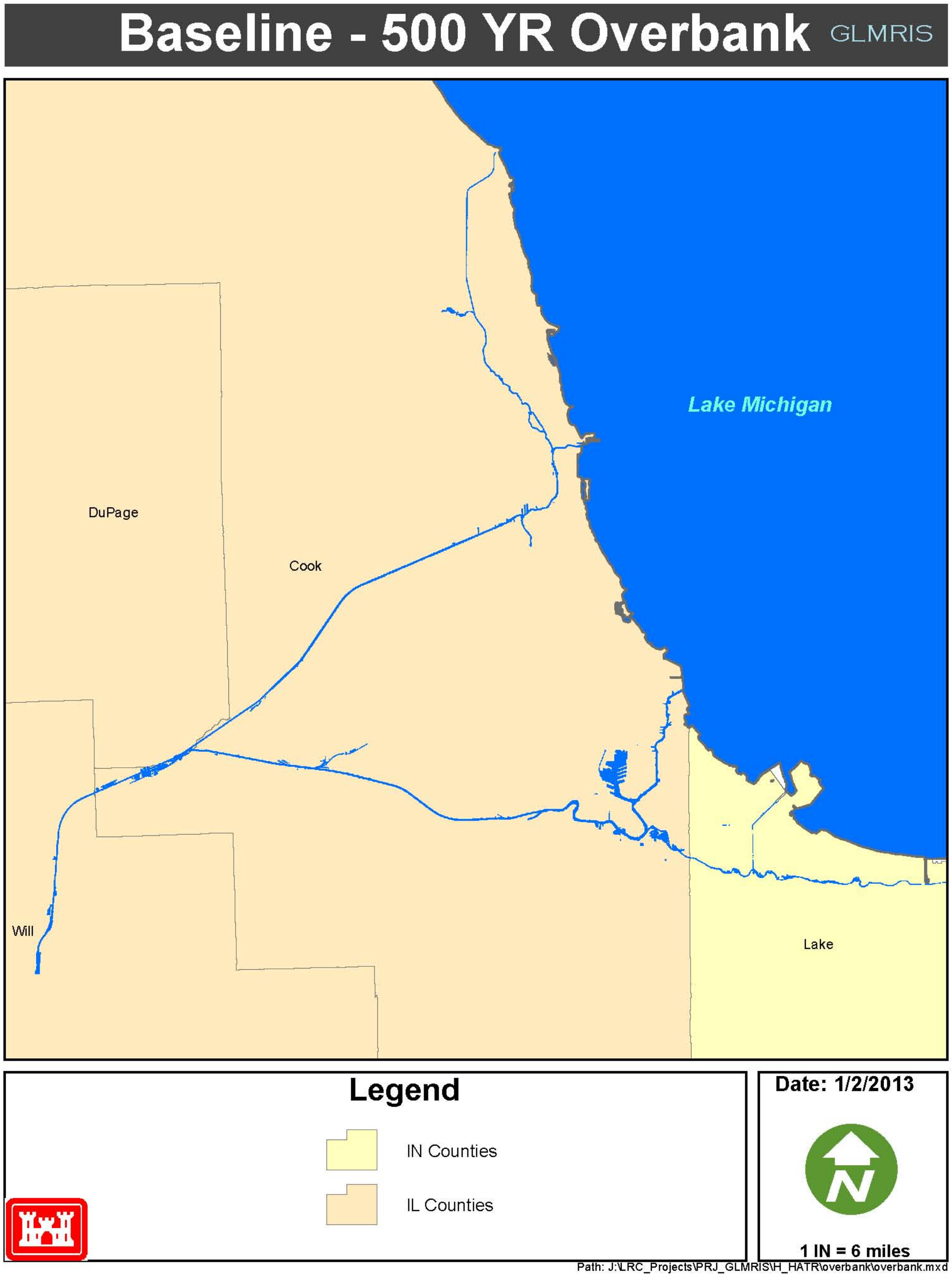

Figure 17 – Inundation Map for the Baseline Condition (500-year event)

Figure 18 – Inundation Map for the Future Condition (500-year event)

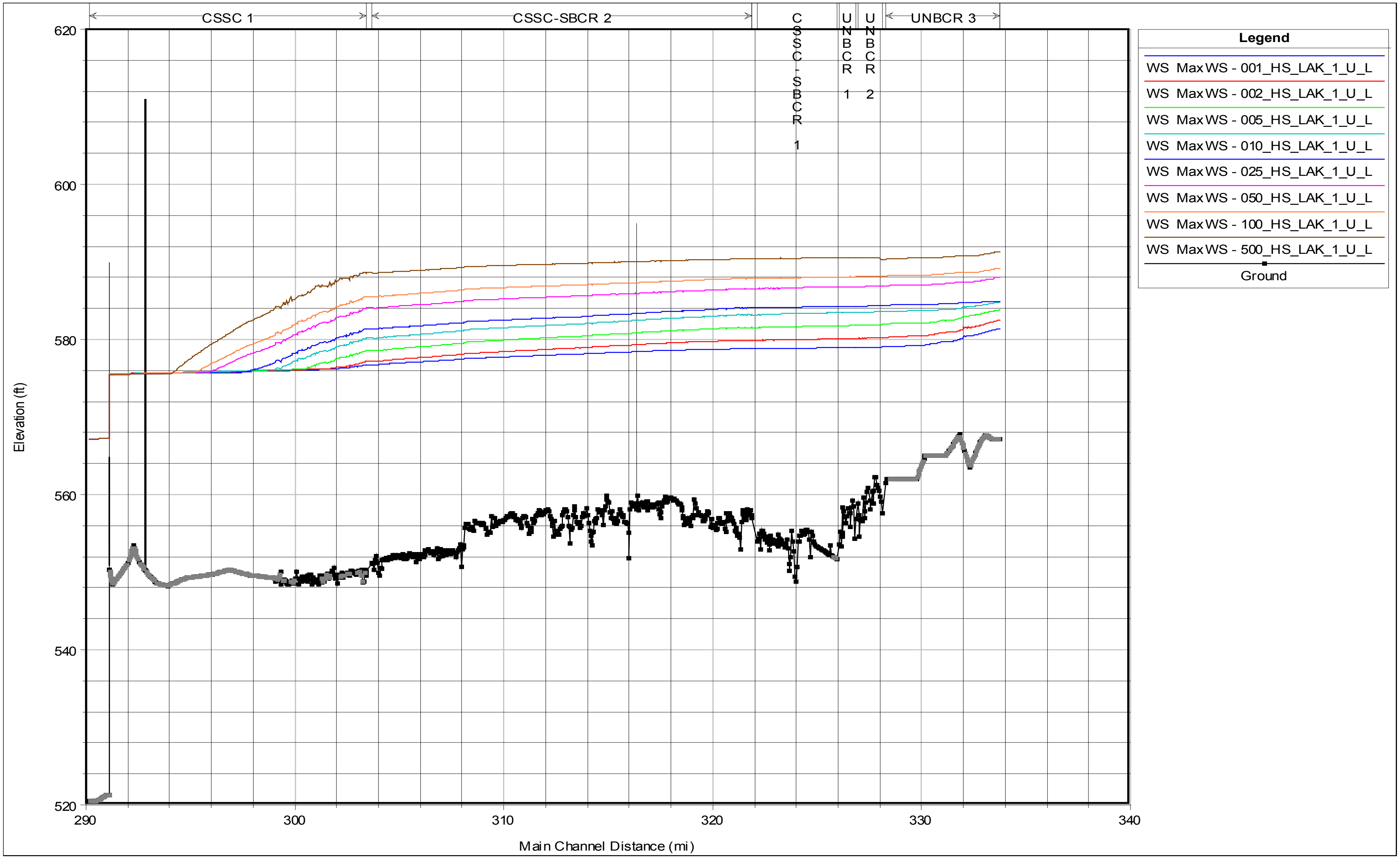

Figure 19 – Maximum Water Levels on the CSSC, SBCR and NBCR for the Baseline Condition with Lakefront Hydrologic Separation

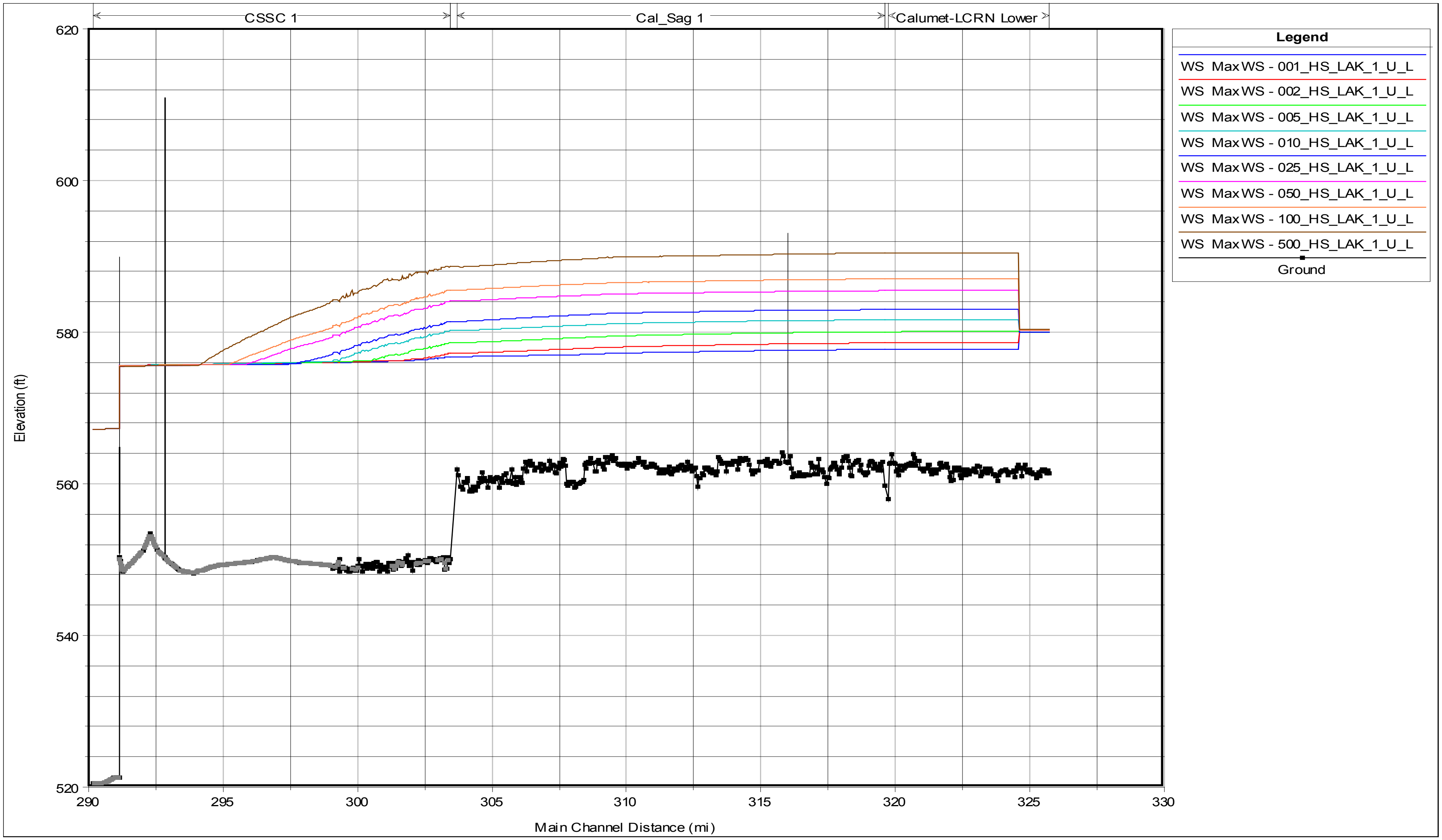

Figure 20 – Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the Baseline Condition with Lakefront Hydrologic Separation

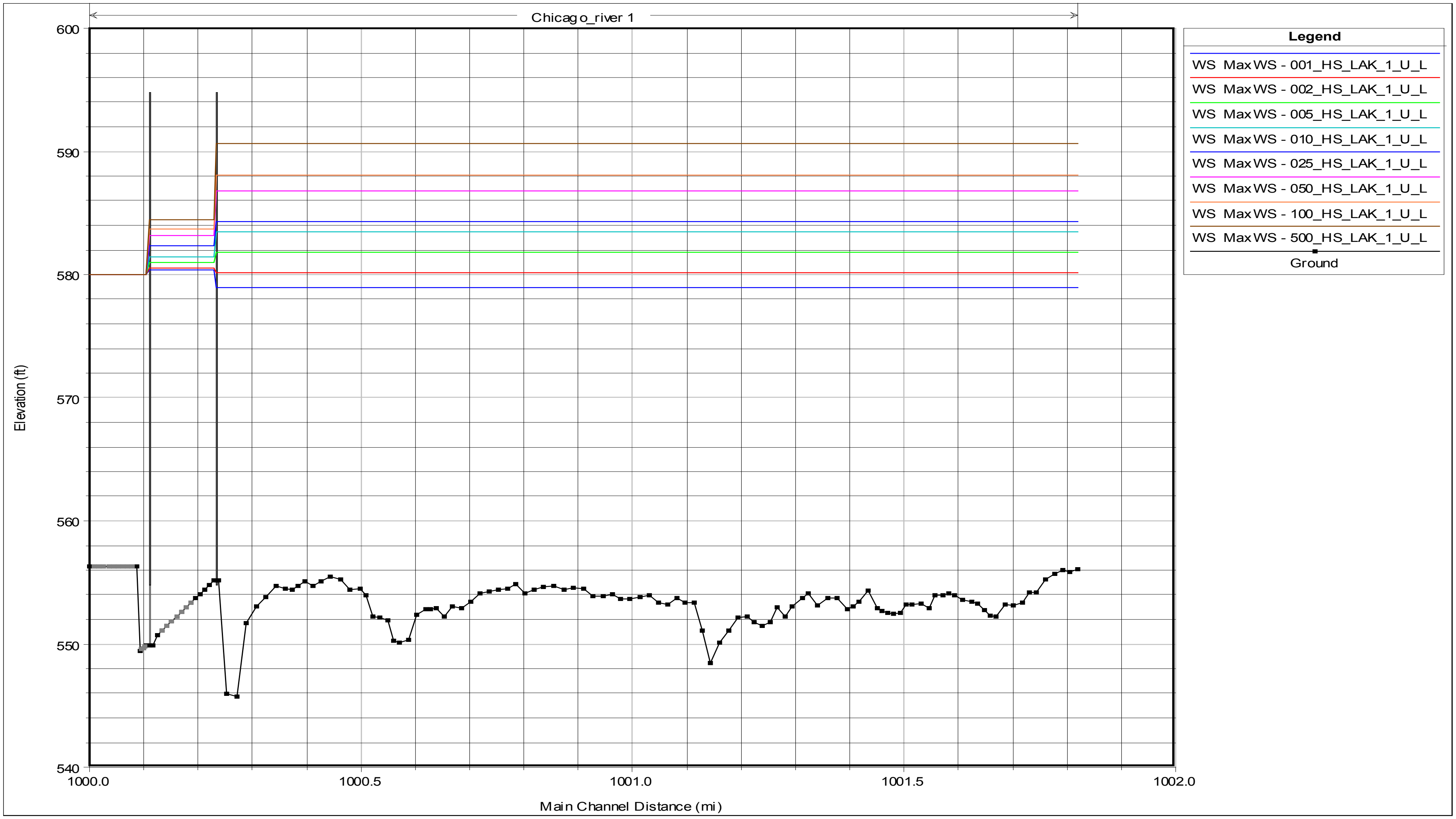

Figure 21 - Maximum Water Surface Elevation on the Chicago River for the Baseline Condition with Lakefront Hydrologic Separation

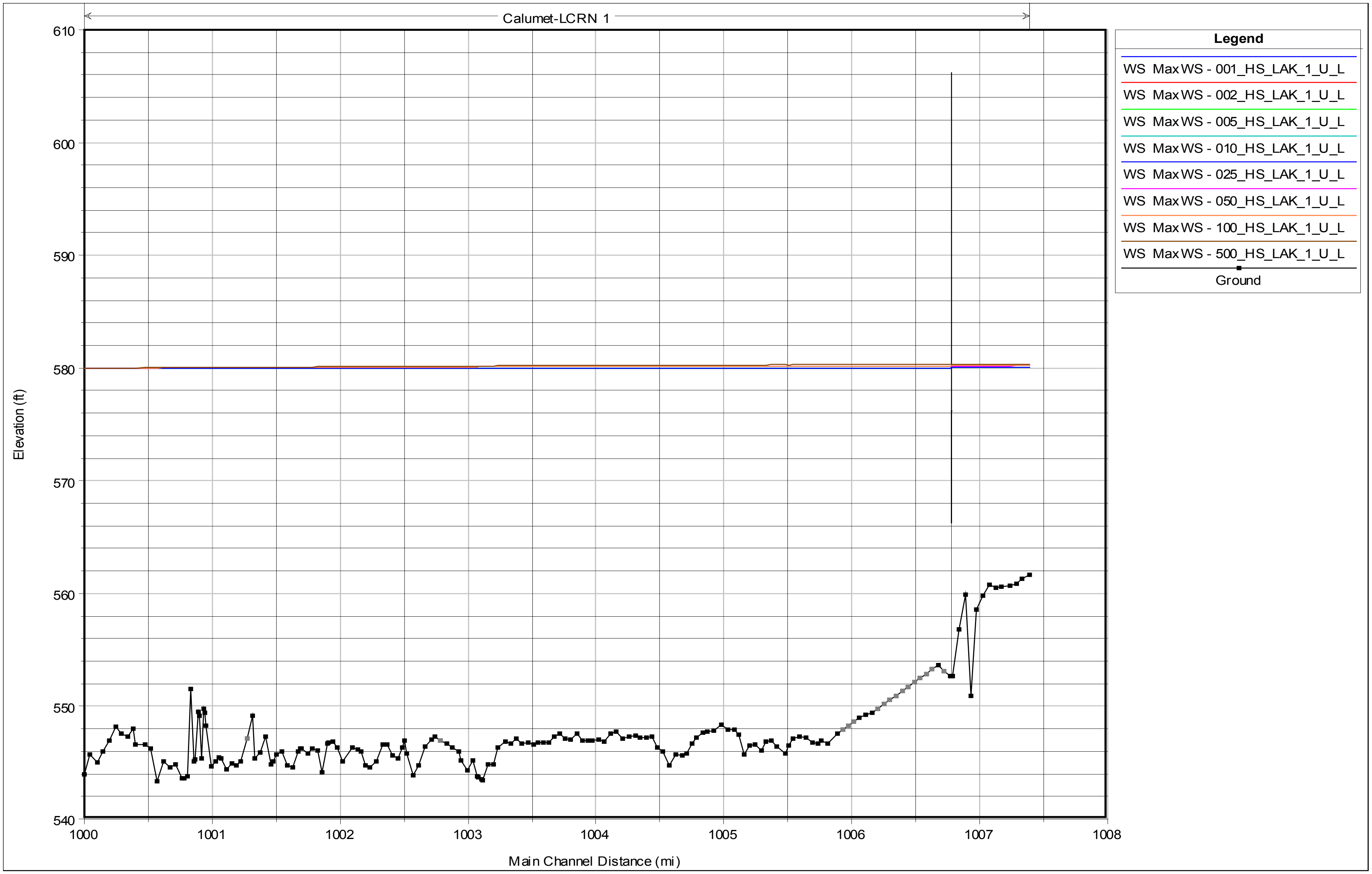

Figure 22 - Maximum Water Surface Elevation on the Calumet River upstream of O'Brien Lock and Dam for the Baseline Condition with Lakefront Hydrologic Separation

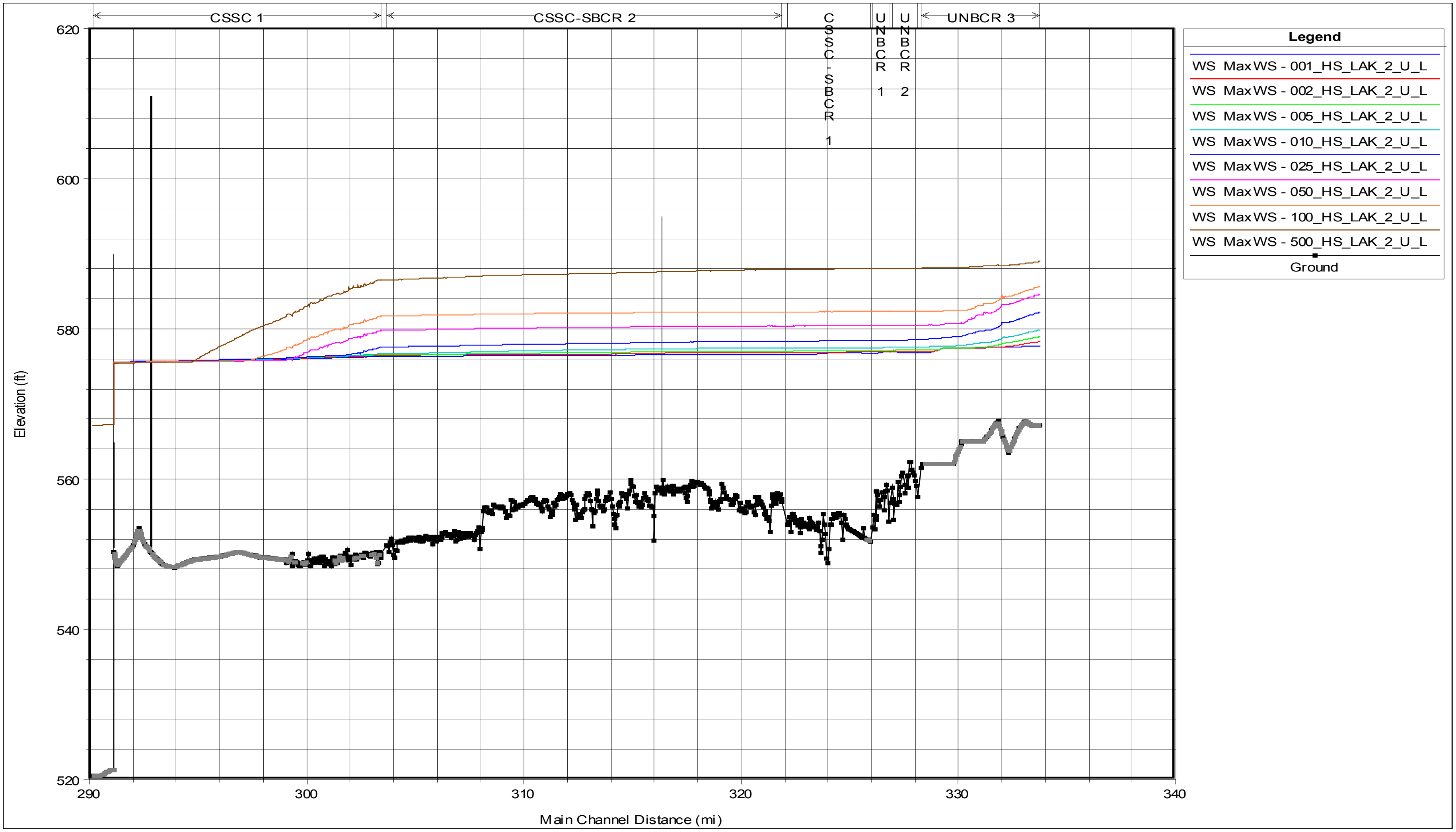

Figure 23 – Maximum Water Levels on the CSSC, SBCR and NBCR for the Future Condition with Lakefront Hydrologic Separation

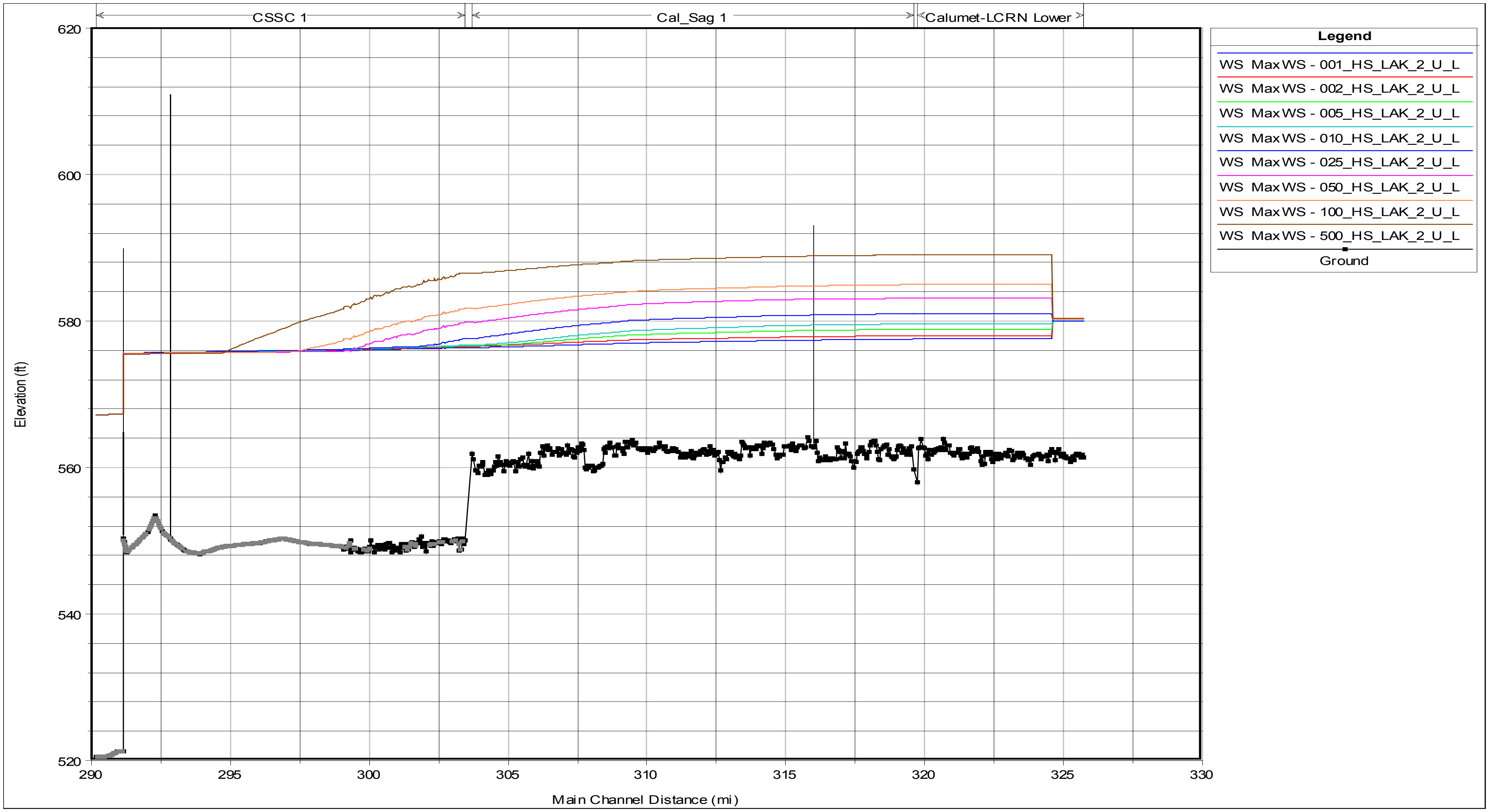

Figure 24 – Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the Future Condition with Lakefront Hydrologic Separation

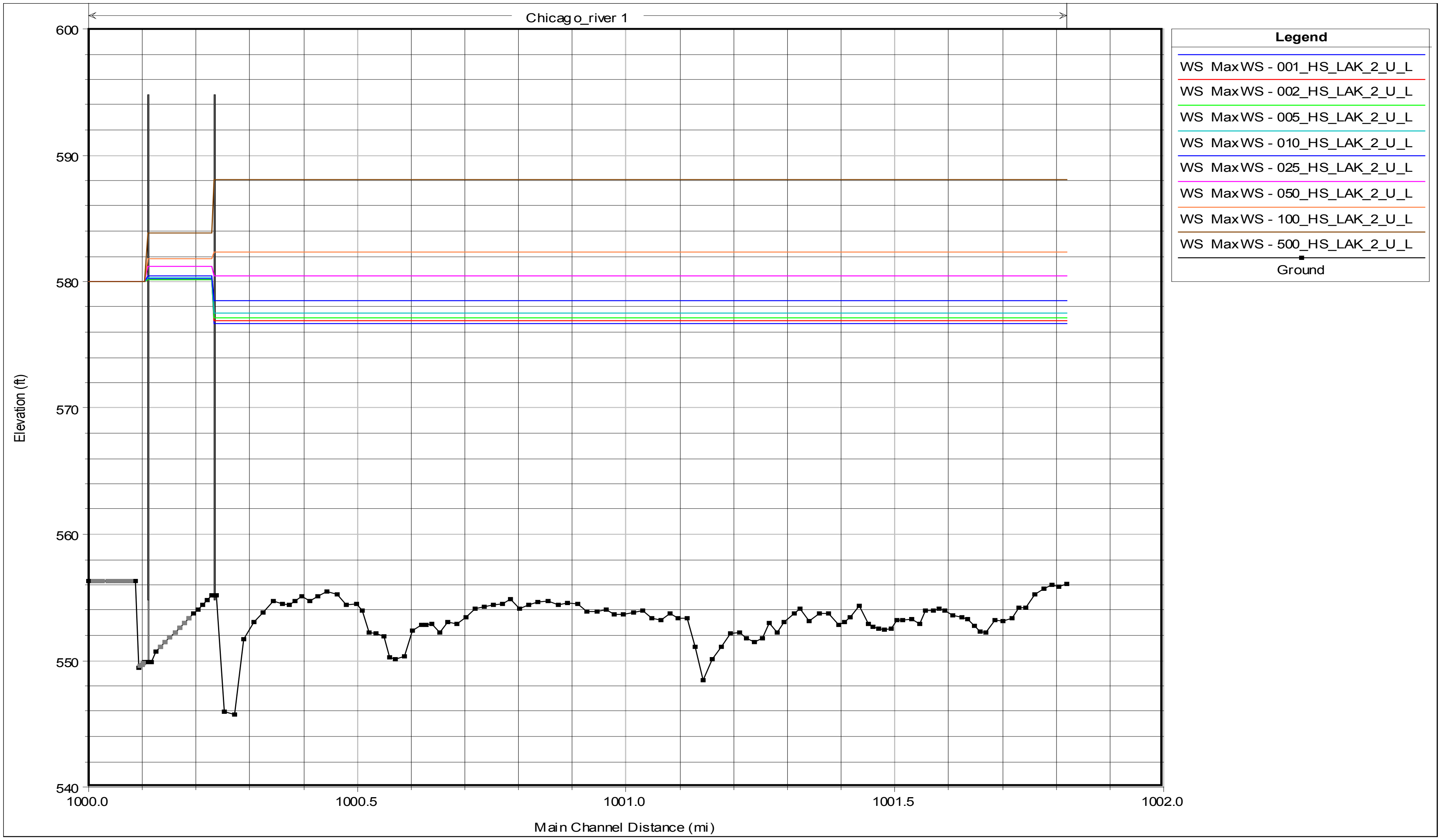

Figure 25 - Maximum Water Surface Elevation on the Chicago River for the Future Condition with Lakefront Hydrologic Separation

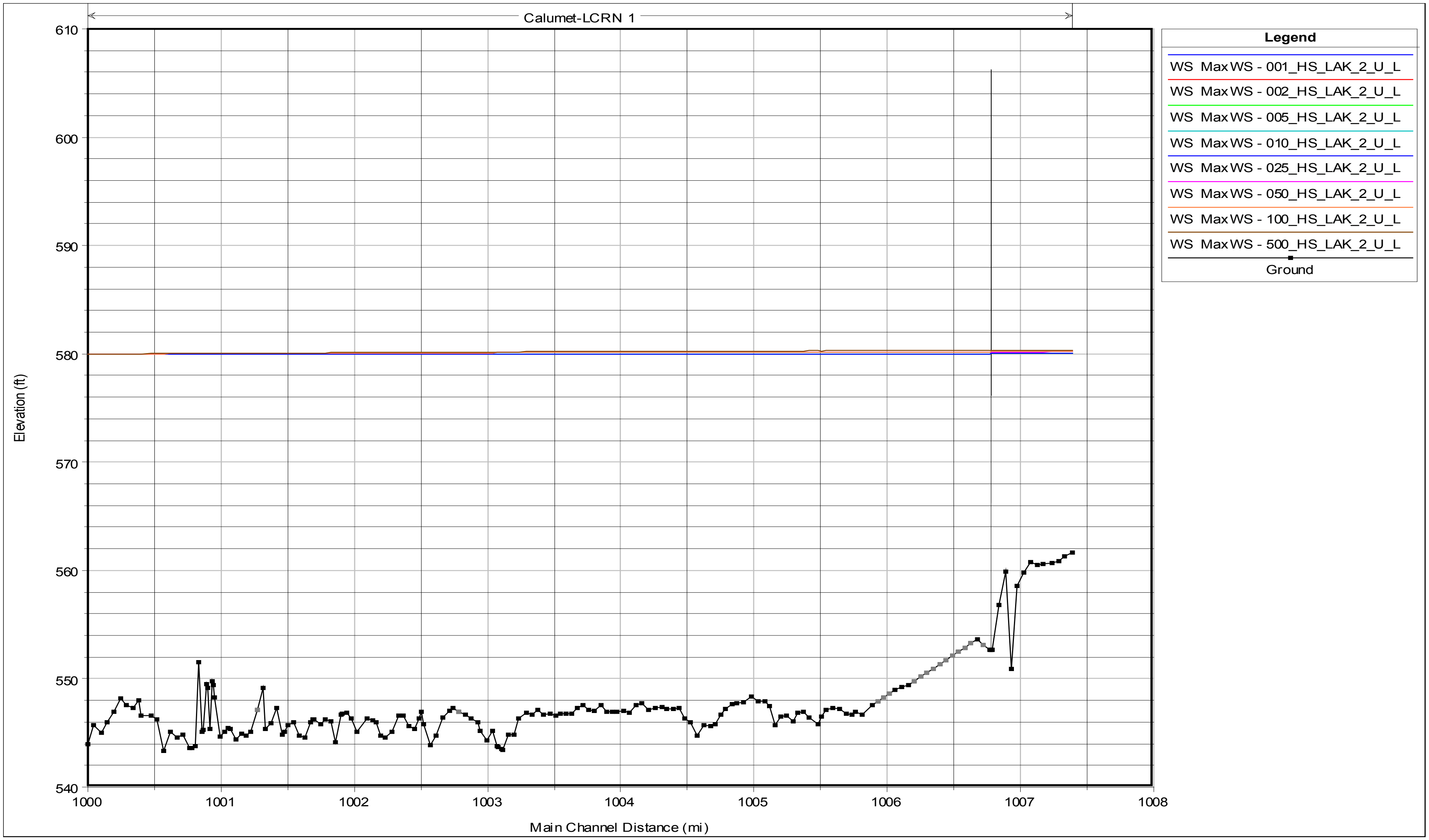

Figure 26 - Maximum Water Surface Elevation on the Calumet River upstream of O’Brien Lock and Dam for the Future Condition with Lakefront Hydrologic Separation

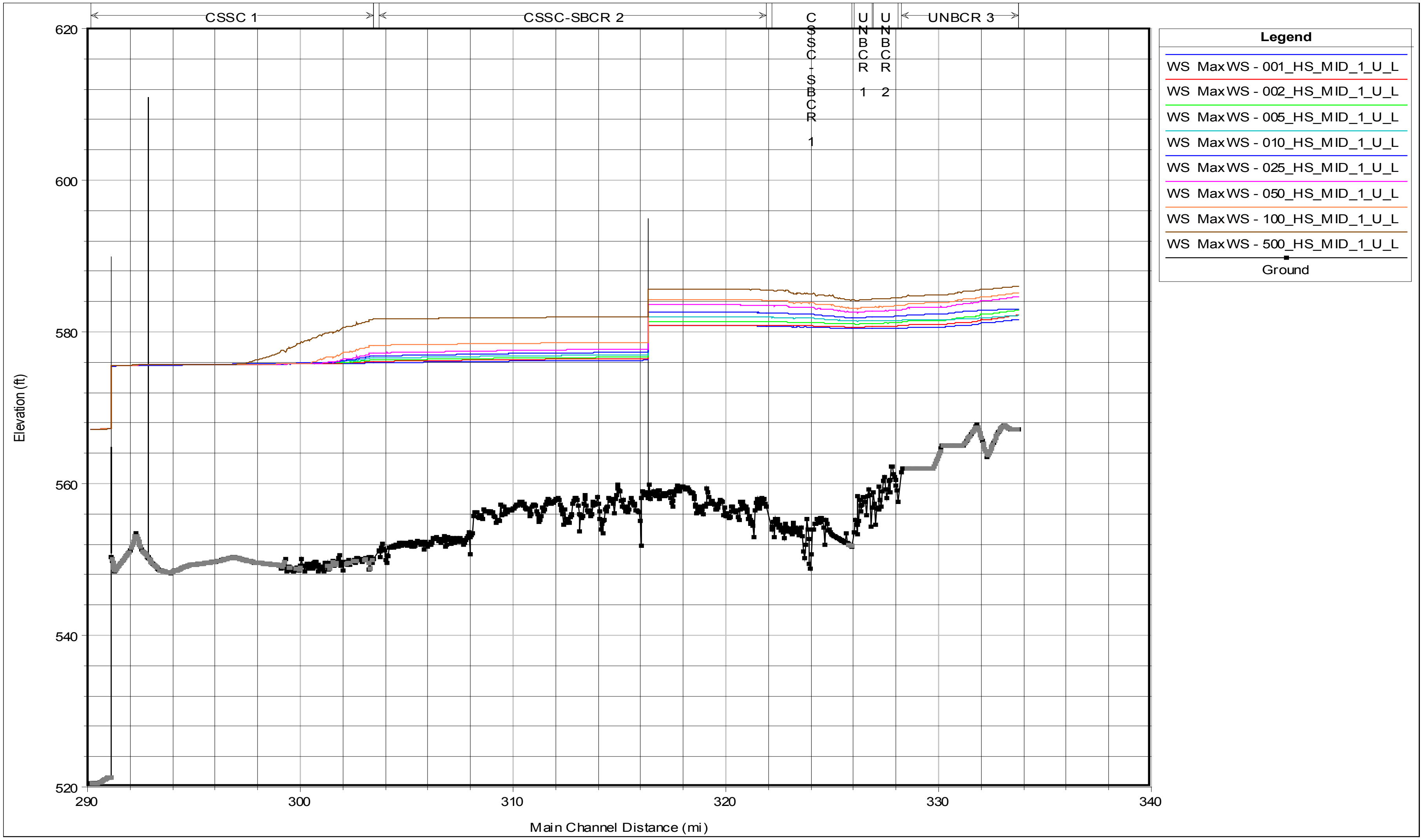

Figure 27 – Maximum Water Levels on the CSSC, SBCR and NBCR for the Baseline Condition with Mid-System Hydrologic Separation

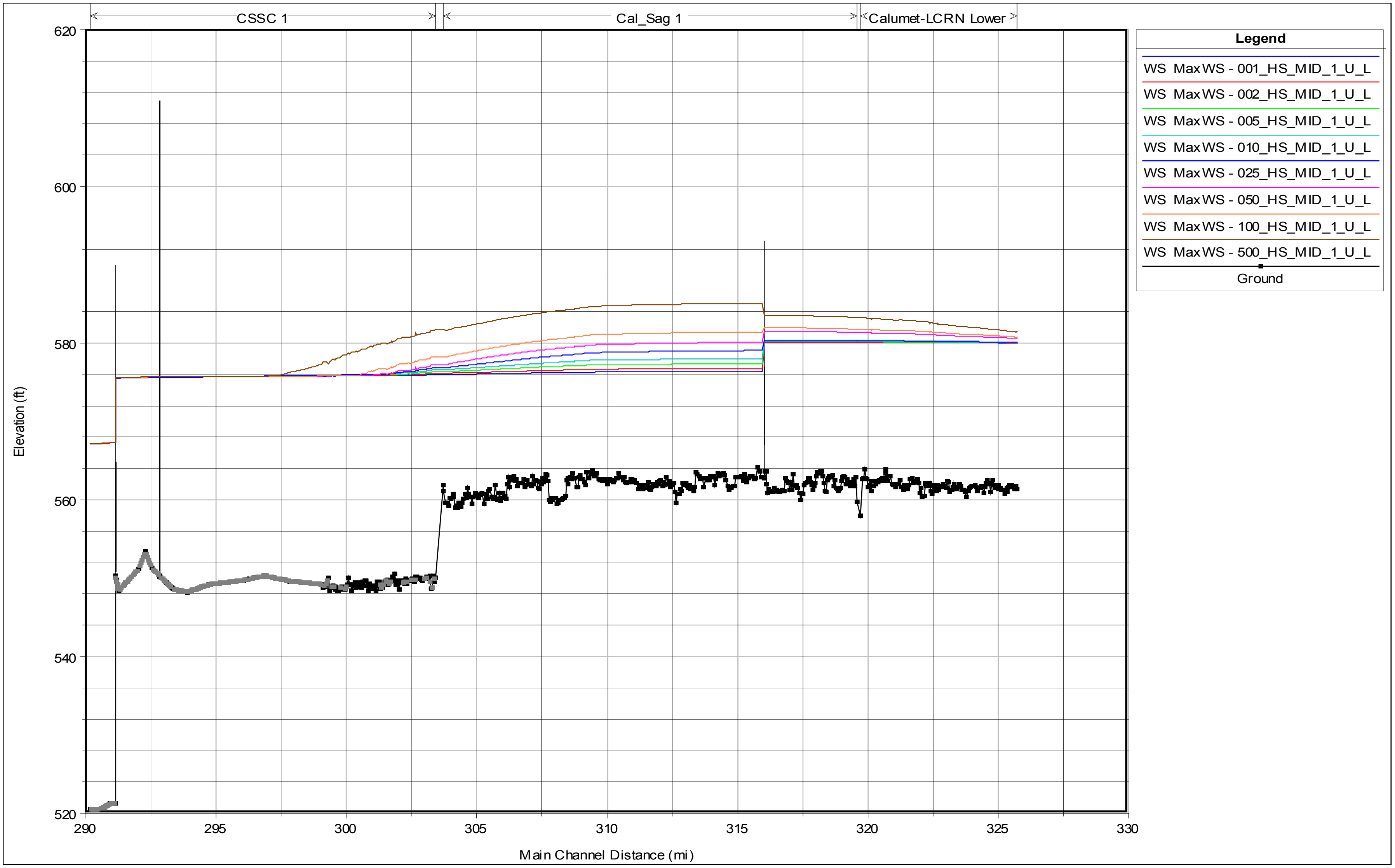

Figure 28 – Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the Baseline Condition with Mid-System Hydrologic Separation

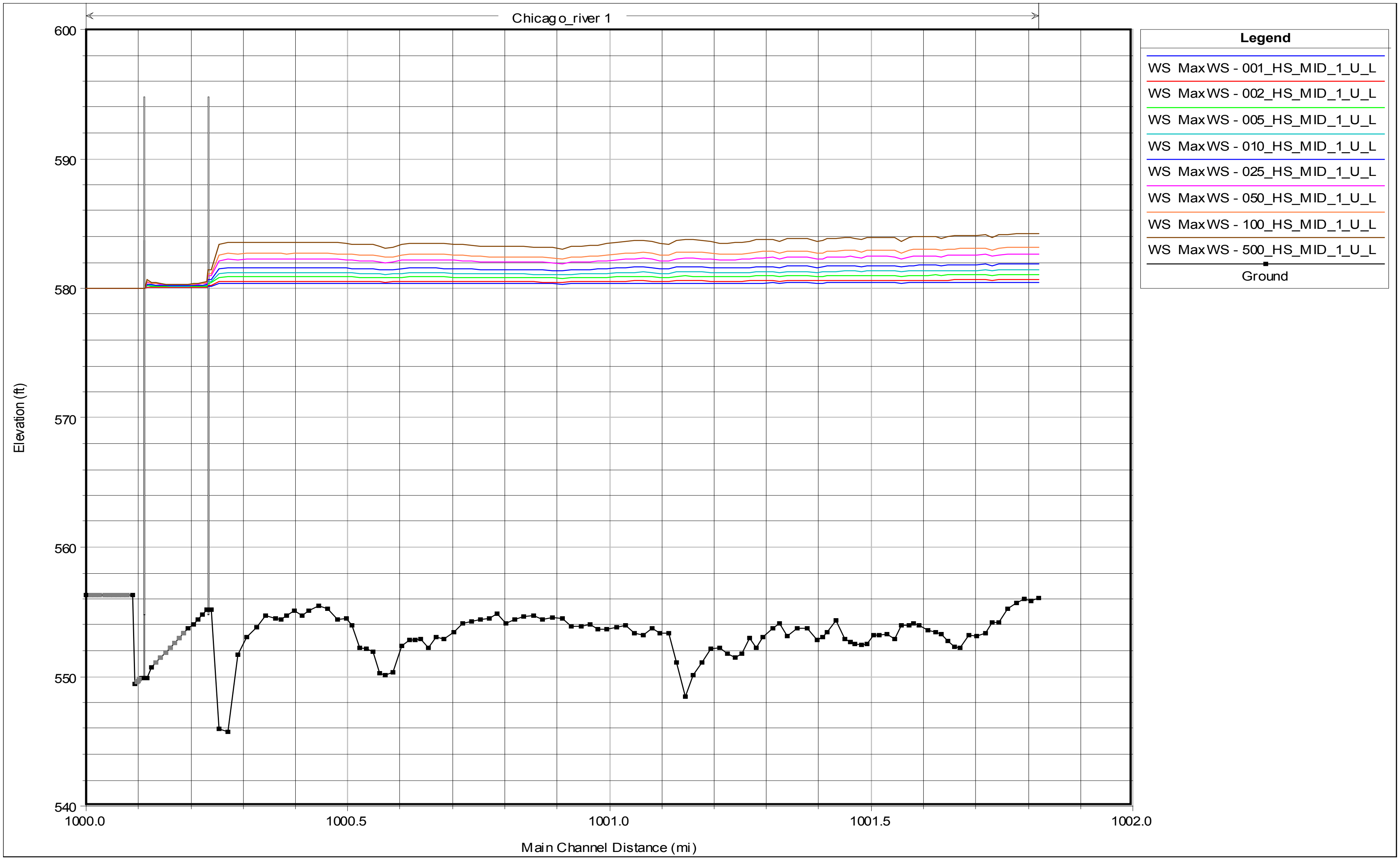

Figure 29 - Maximum Water Surface Elevation on the Chicago River for the Baseline Condition with Mid-System Hydrologic Separation

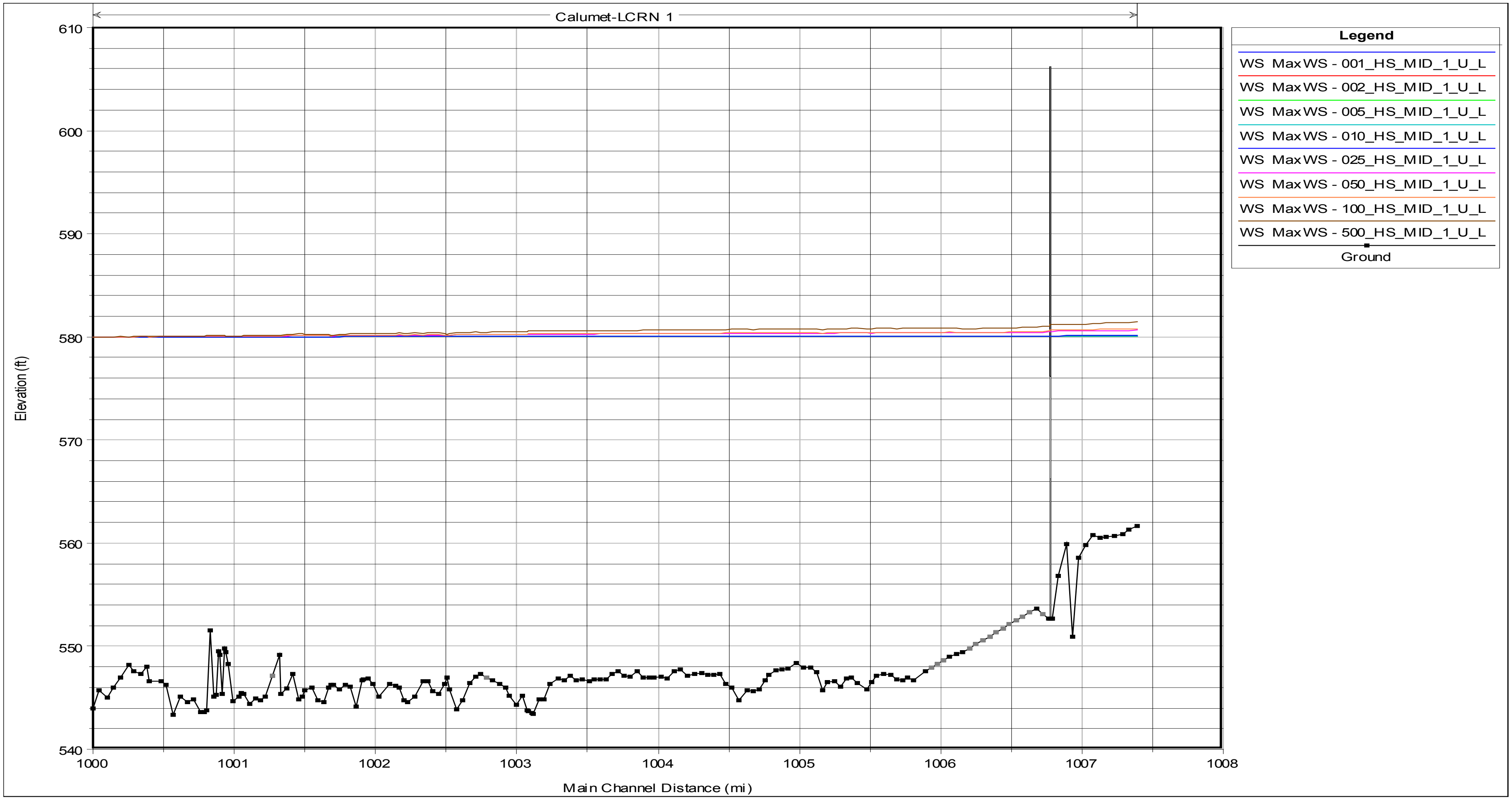

Figure 30 - Maximum Water Surface Elevation on the Calumet River upstream of O'Brien Lock and Dam for the Baseline Condition with Mid-System Hydrologic Separation

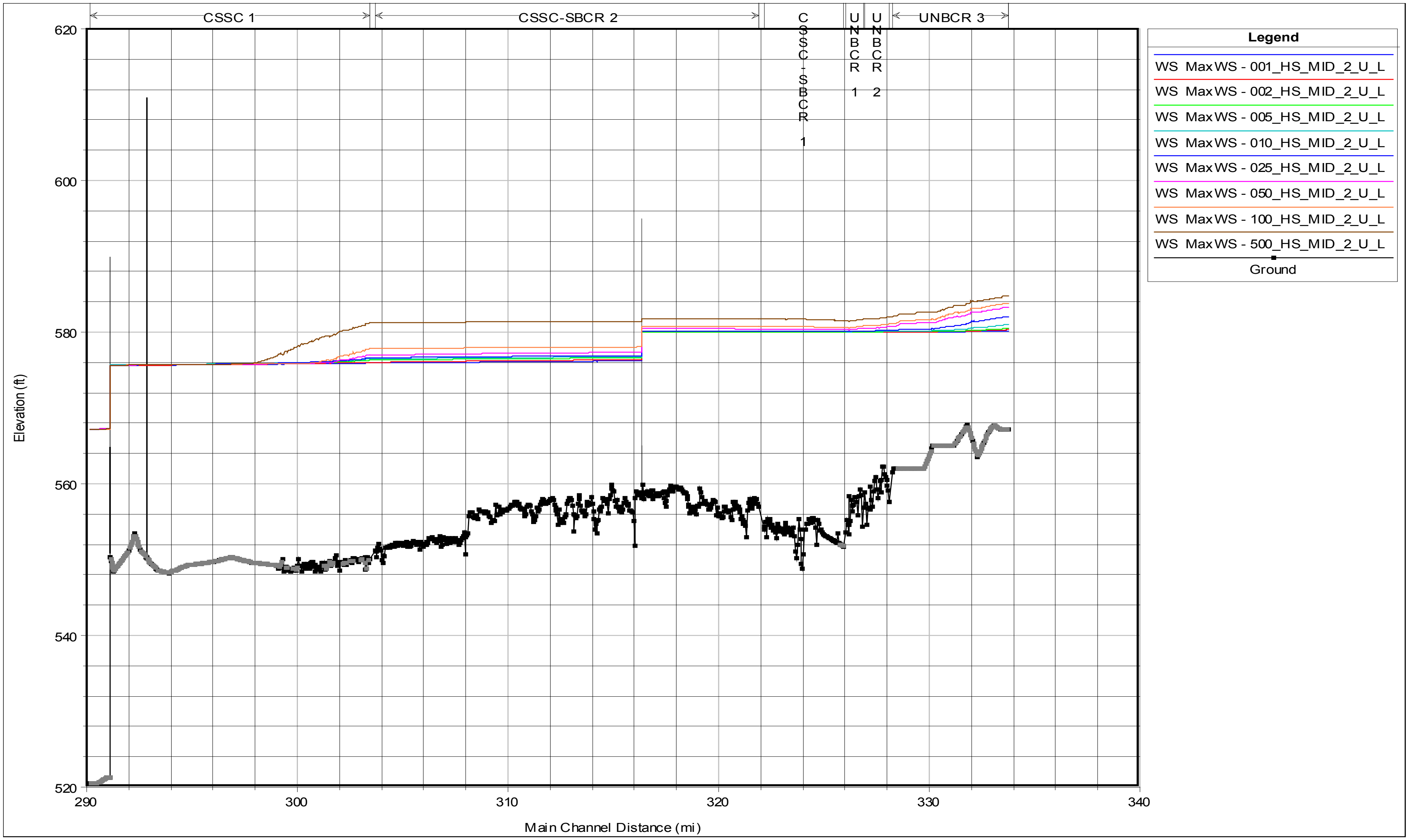

Figure 31 – Maximum Water Levels on the CSSC, SBCR and NBCR for the Future Condition with Mid-System Hydrologic Separation

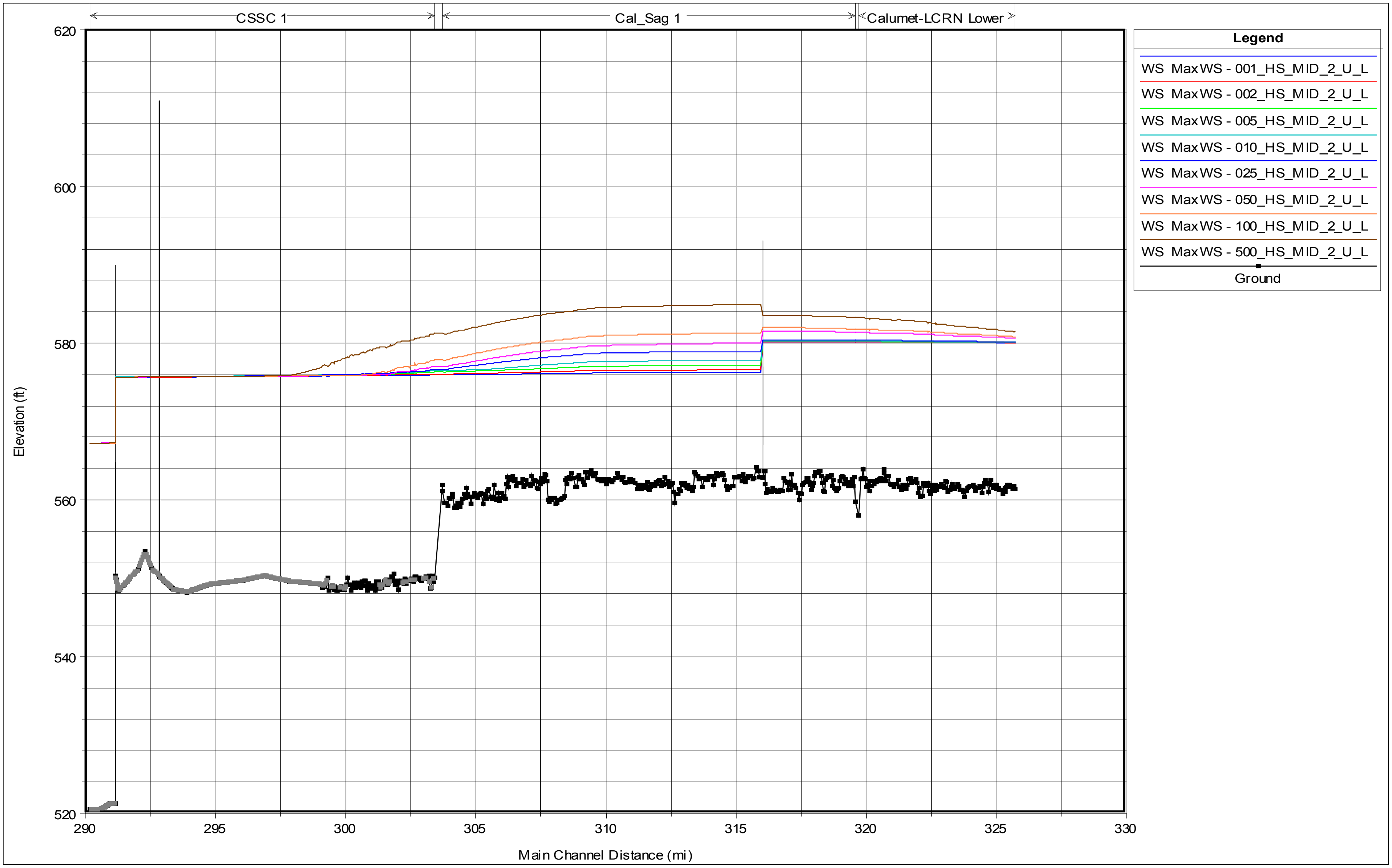

Figure 32 – Maximum Water Levels on the CSSC, Cal-Sag Channel and North Little Calumet River for the Future Condition with Mid-System Hydrologic Separation

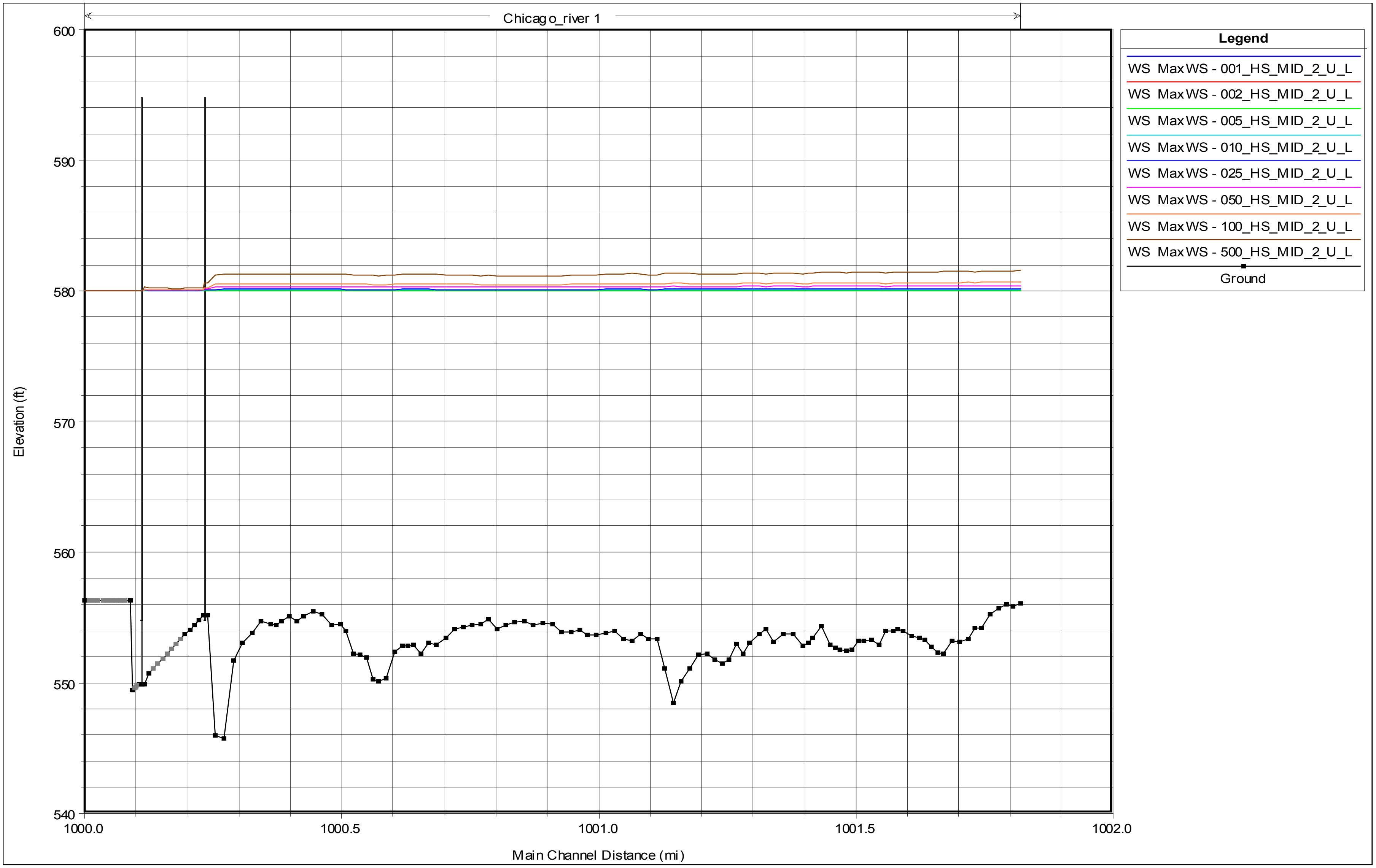

Figure 33 - Maximum Water Surface Elevation on the Chicago River for the Future Condition with Mid-System Hydrologic Separation

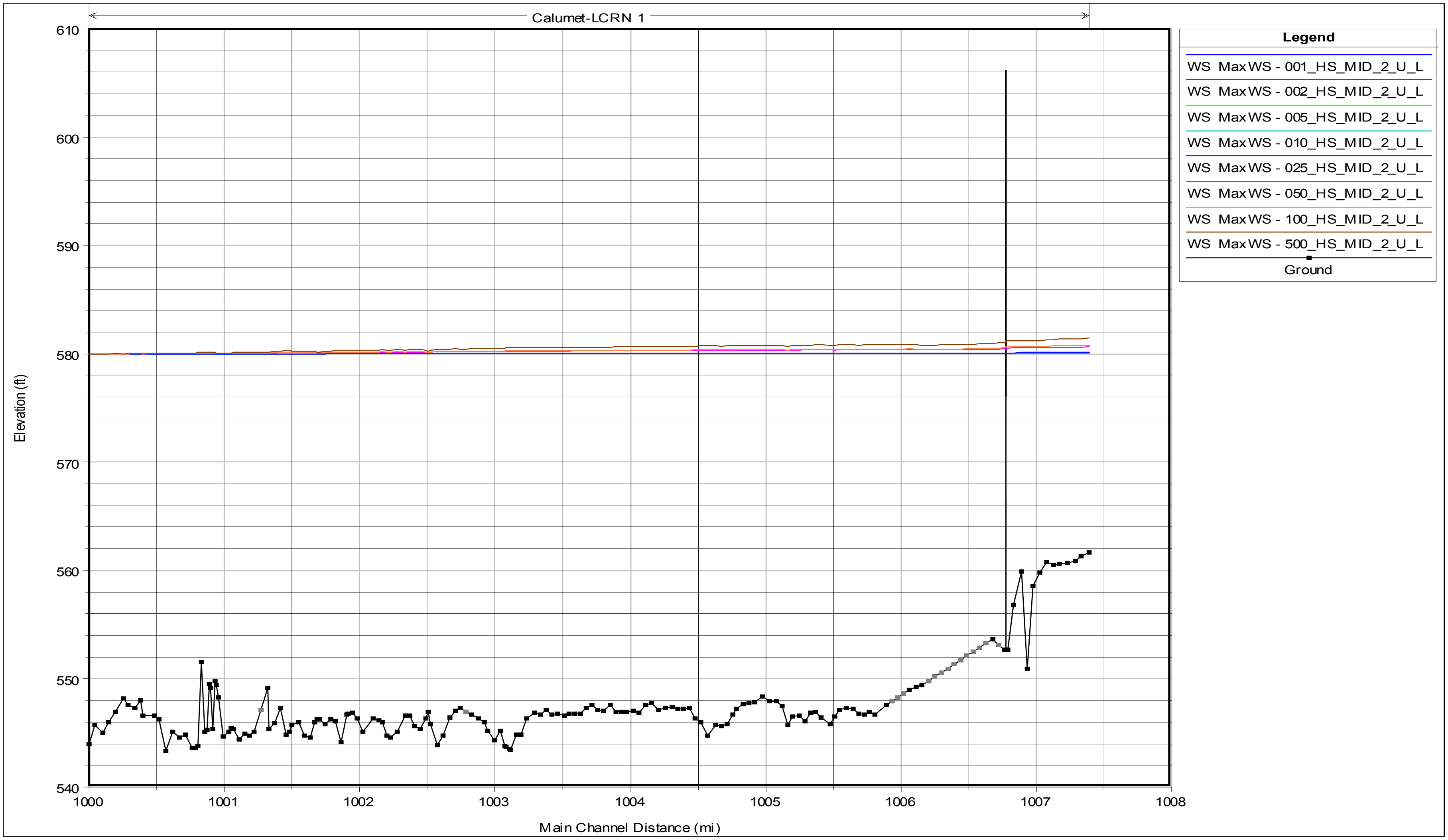

Figure 34 - Maximum Water Surface Elevation on the Calumet River upstream of O'Brien Lock and Dam for the Future Condition with Mid-System Hydrologic Separation

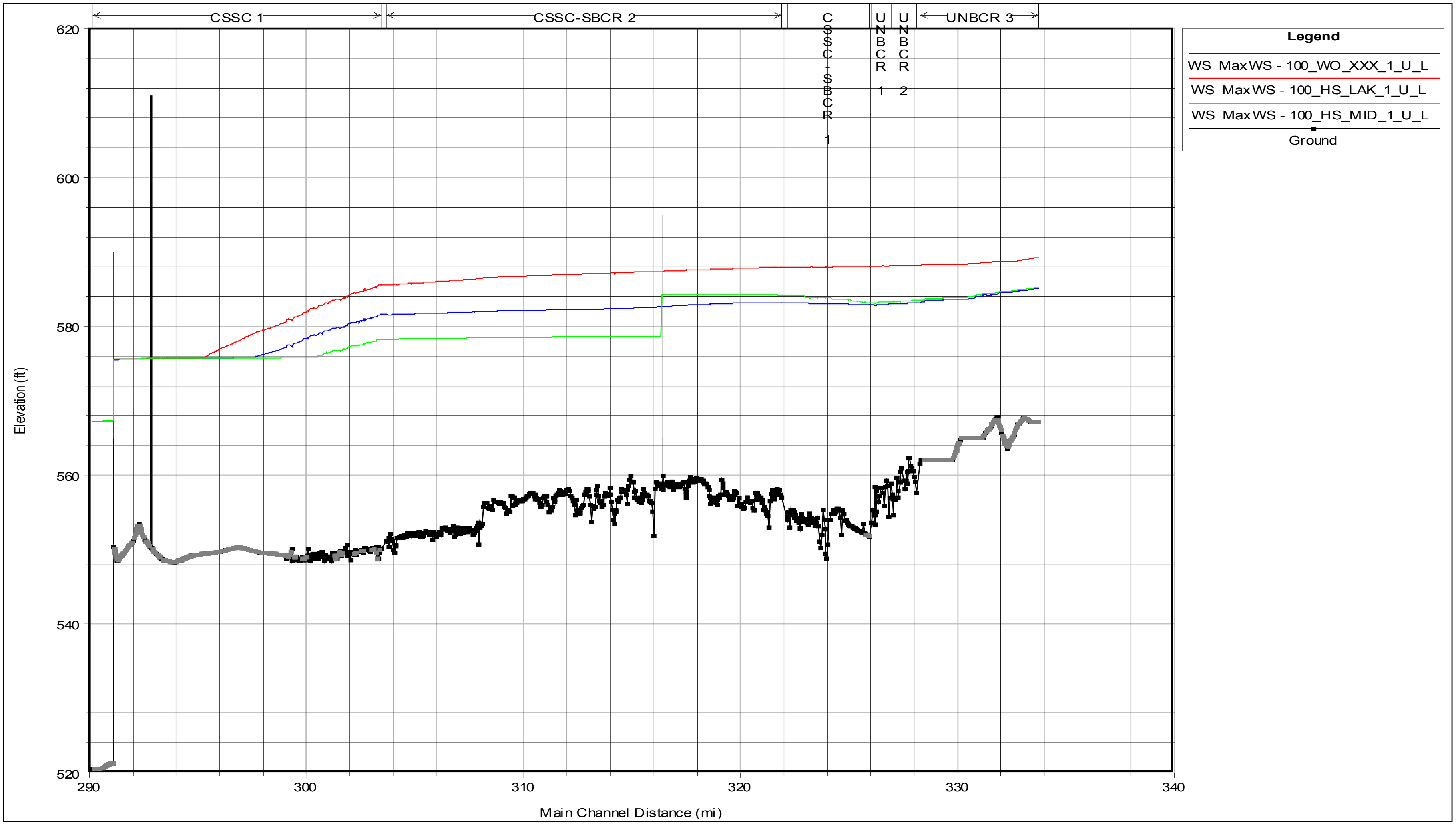

Figure 35 – Comparison of 100 year Maximum Water Levels on the CSSC, SBCR and NBCR for the Baseline Condition, Baseline Condition with Lakefront Hydrologic Separation and Baseline Condition with Mid-System Hydrologic Separation

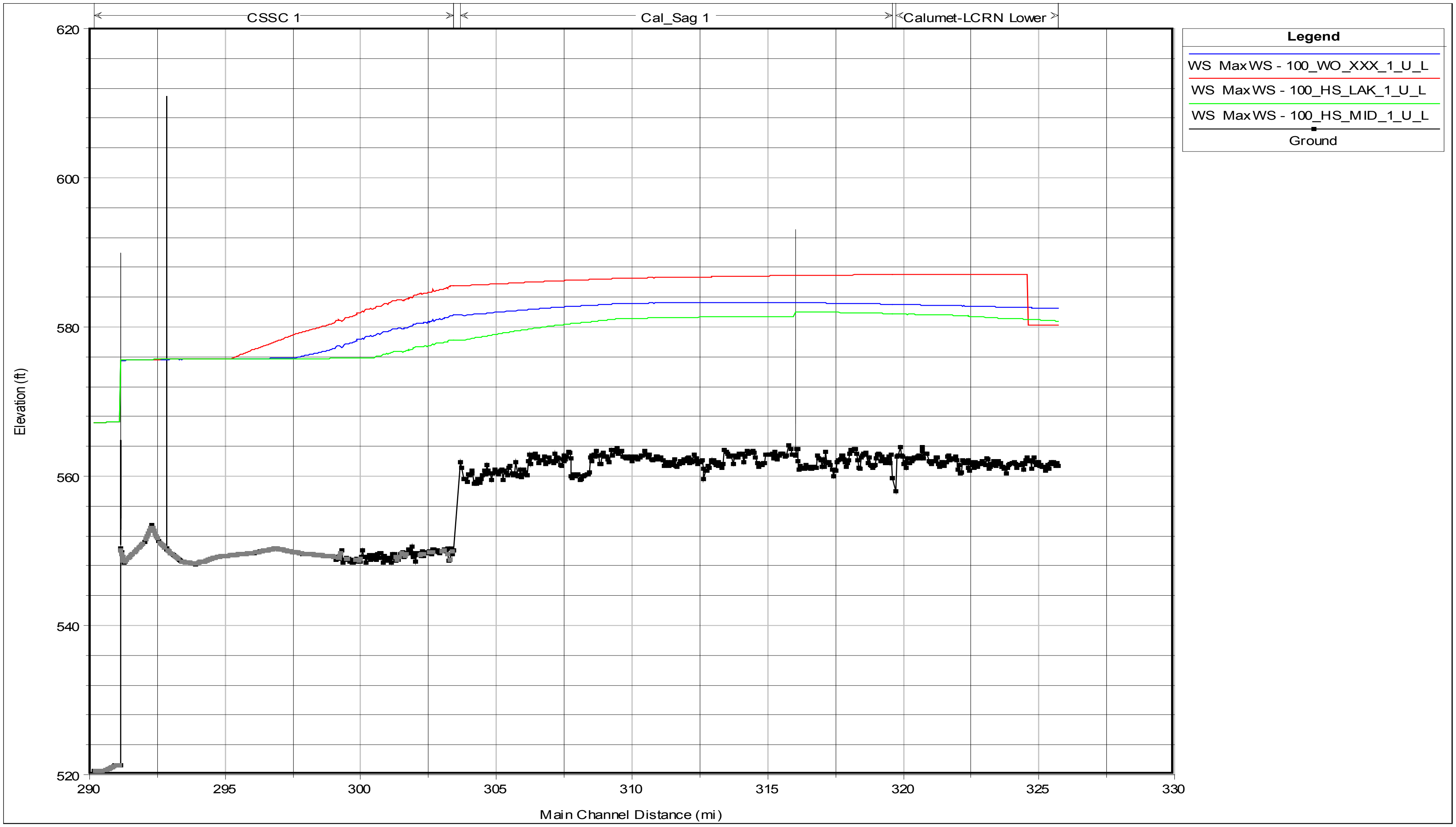

Figure 36 – Comparison of 100 year Maximum Water Levels on the CSSC , Cal-Sag Channel and North Little Calumet River for the Baseline Condition, Baseline Condition with Lakefront Hydrologic Separation and Baseline Condition with Mid-System Hydrologic Separation

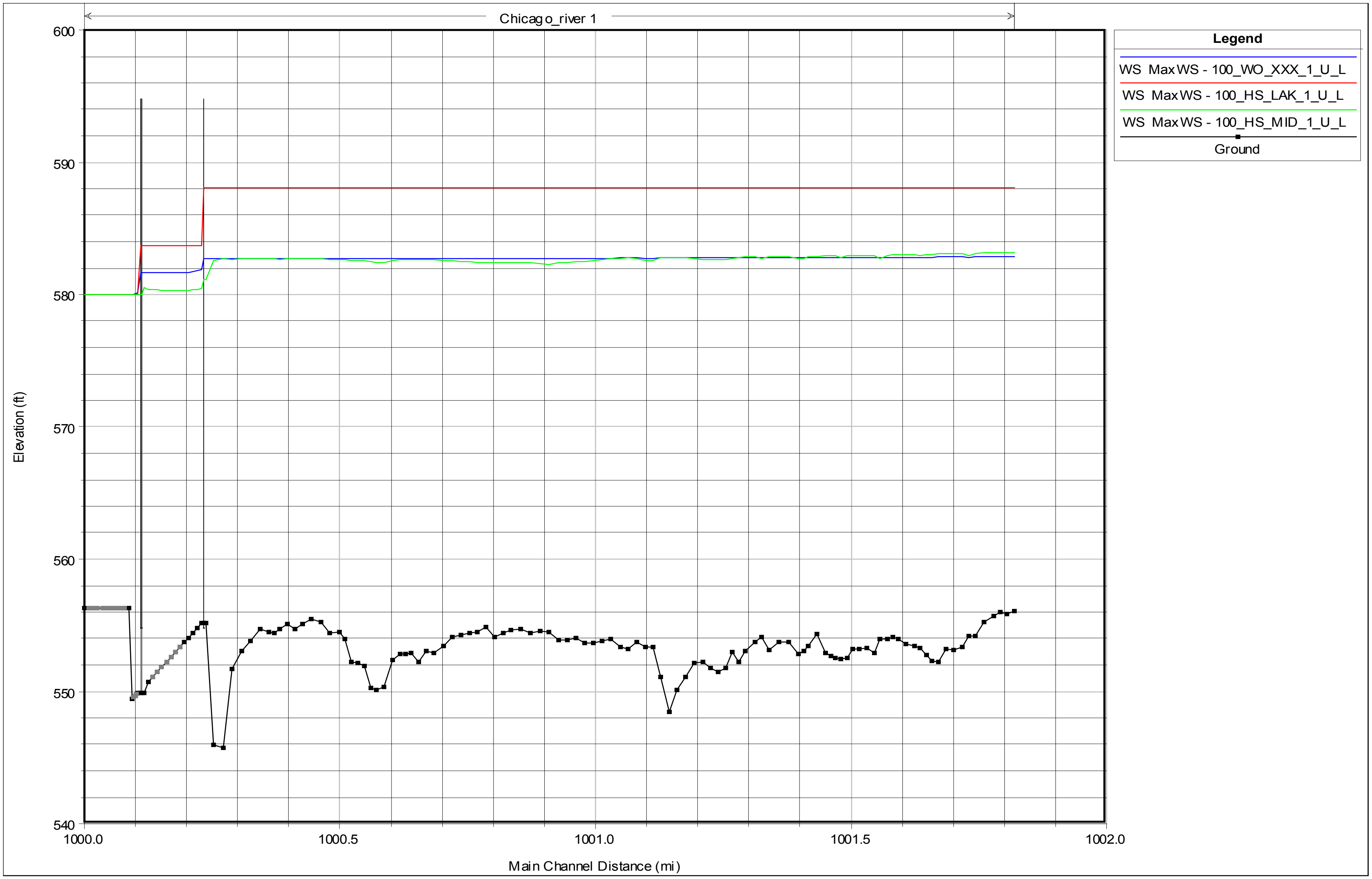

Figure 37 – Comparison of 100 year Maximum Water Levels on the Chicago River for the Baseline Condition, Baseline Condition with Lakefront Hydrologic Separation and Baseline Condition with Mid-System Hydrologic Separation

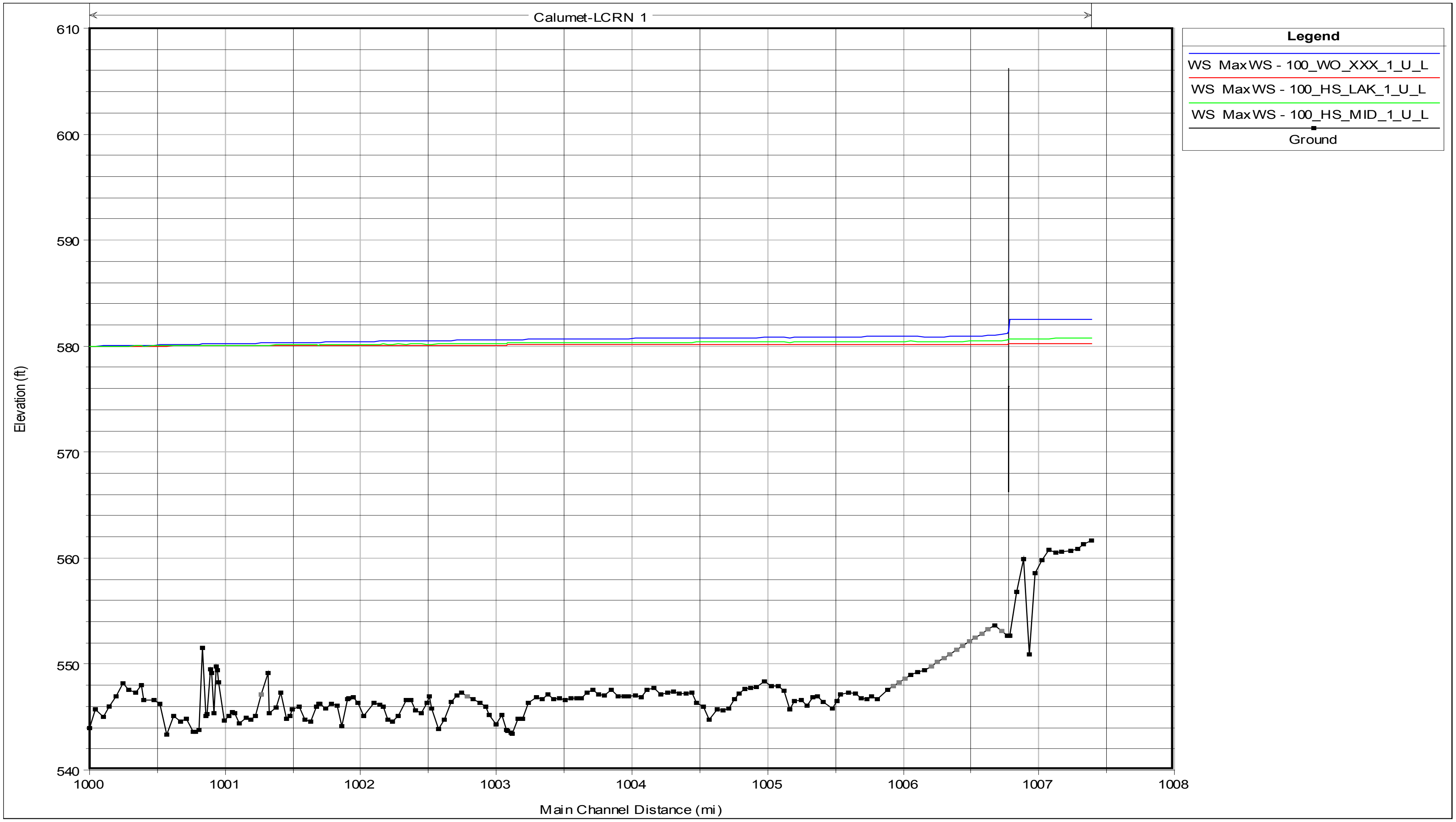

Figure 38 – Comparison of 100 year Maximum Water Levels on the Calumet River upstream of O'Brien Lock and Dam for the Baseline Condition, Baseline Condition with Lakefront Hydrologic Separation and Baseline Condition with Mid-System Hydrologic Separation

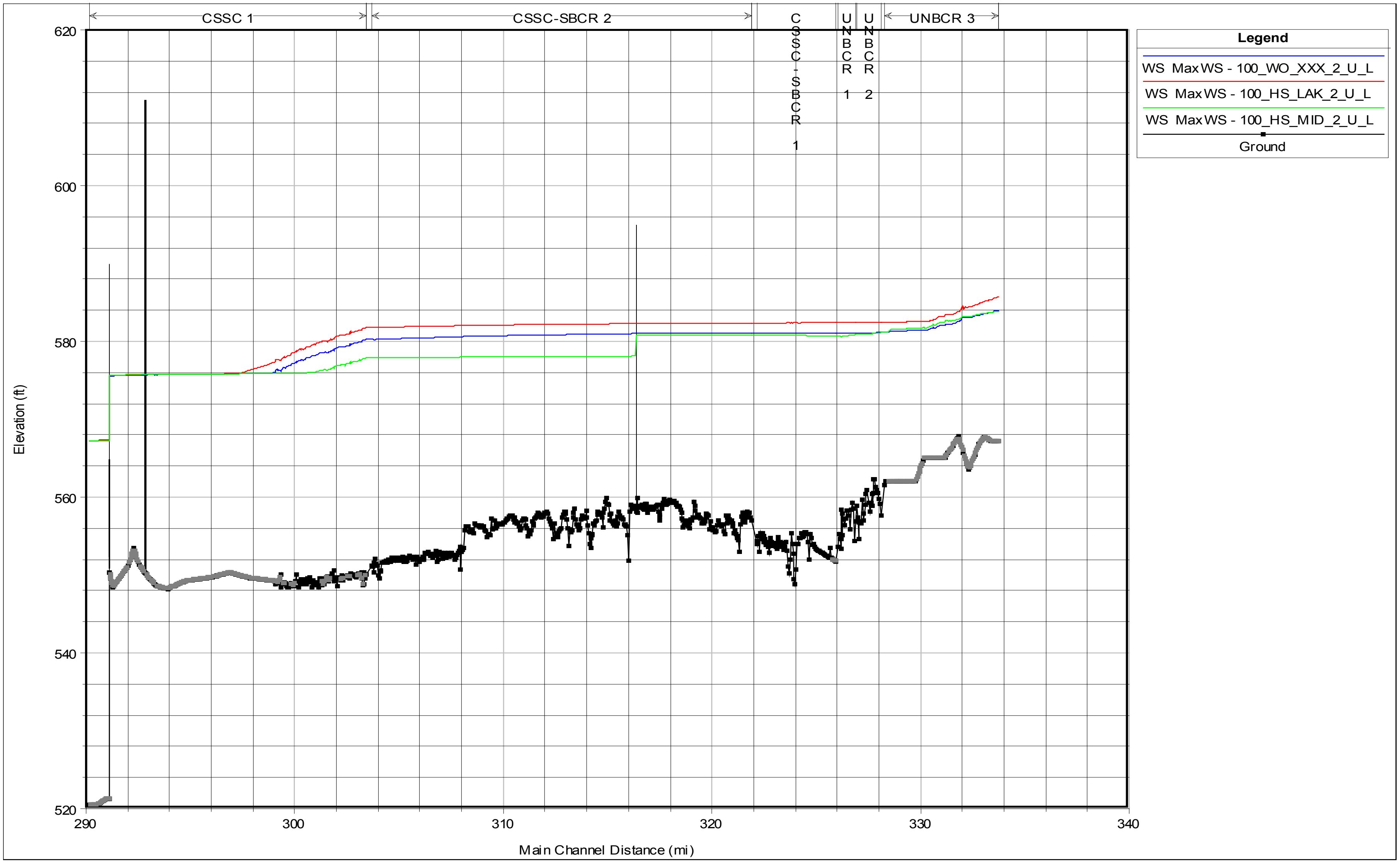

Figure 39 – Comparison of 100 year Maximum Water Levels on the CSSC, SBCR and NBCR for the Future Condition, Future Condition with Lakefront Hydrologic Separation and Future Condition with Mid-System Hydrologic Separation

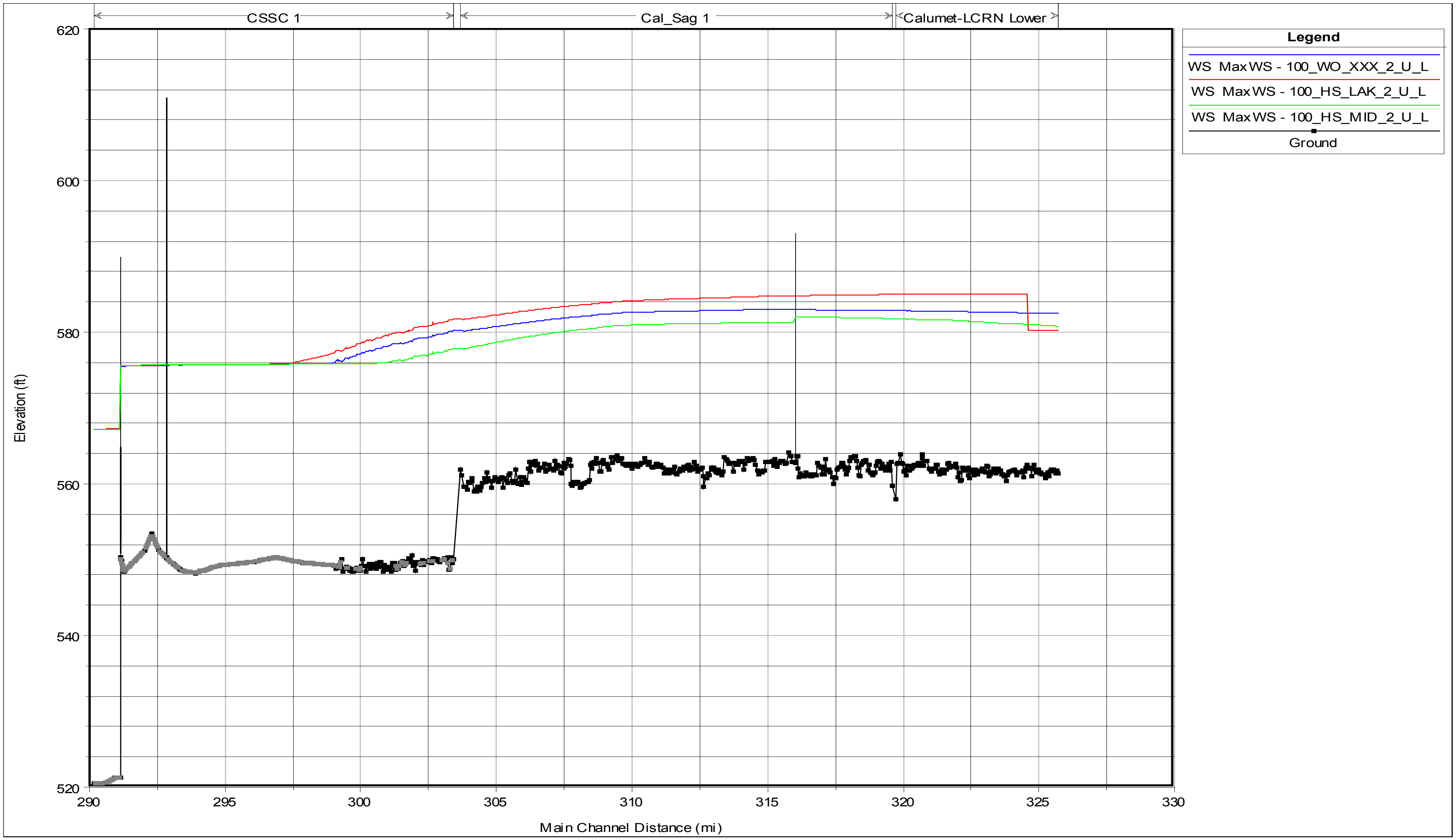

Figure 40 – Comparison of 100 year Maximum Water Levels on the CSSC , Cal-Sag Channel and North Little Calumet River for the Future Condition, Future Condition with Lakefront Hydrologic Separation and Future Condition with Mid-System Hydrologic Separation

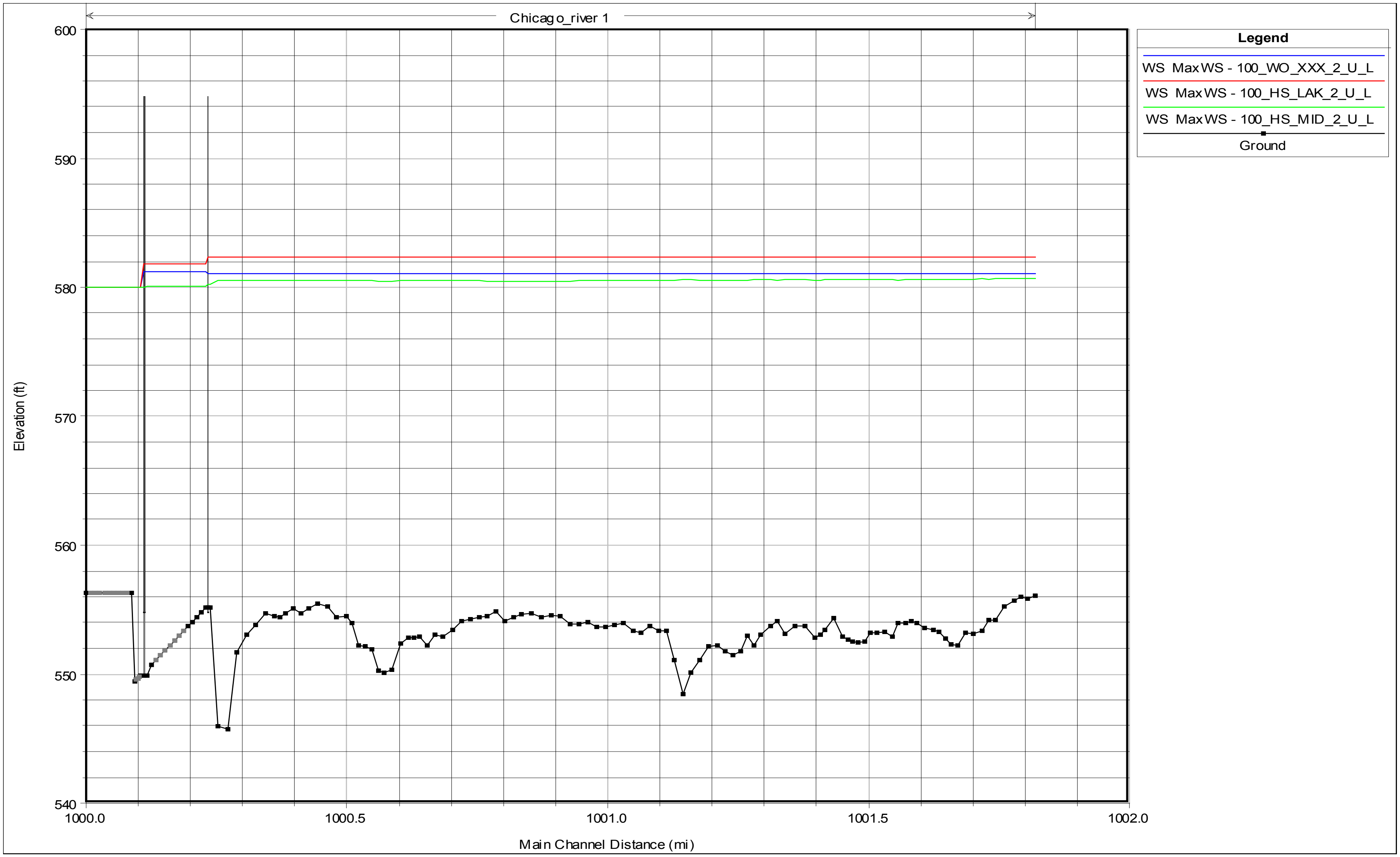

Figure 41 – Comparison of 100 year Maximum Water Levels on the Chicago River for the Future Condition, Future Condition with Lakefront Hydrologic Separation and Future Condition with Mid-System Hydrologic Separation

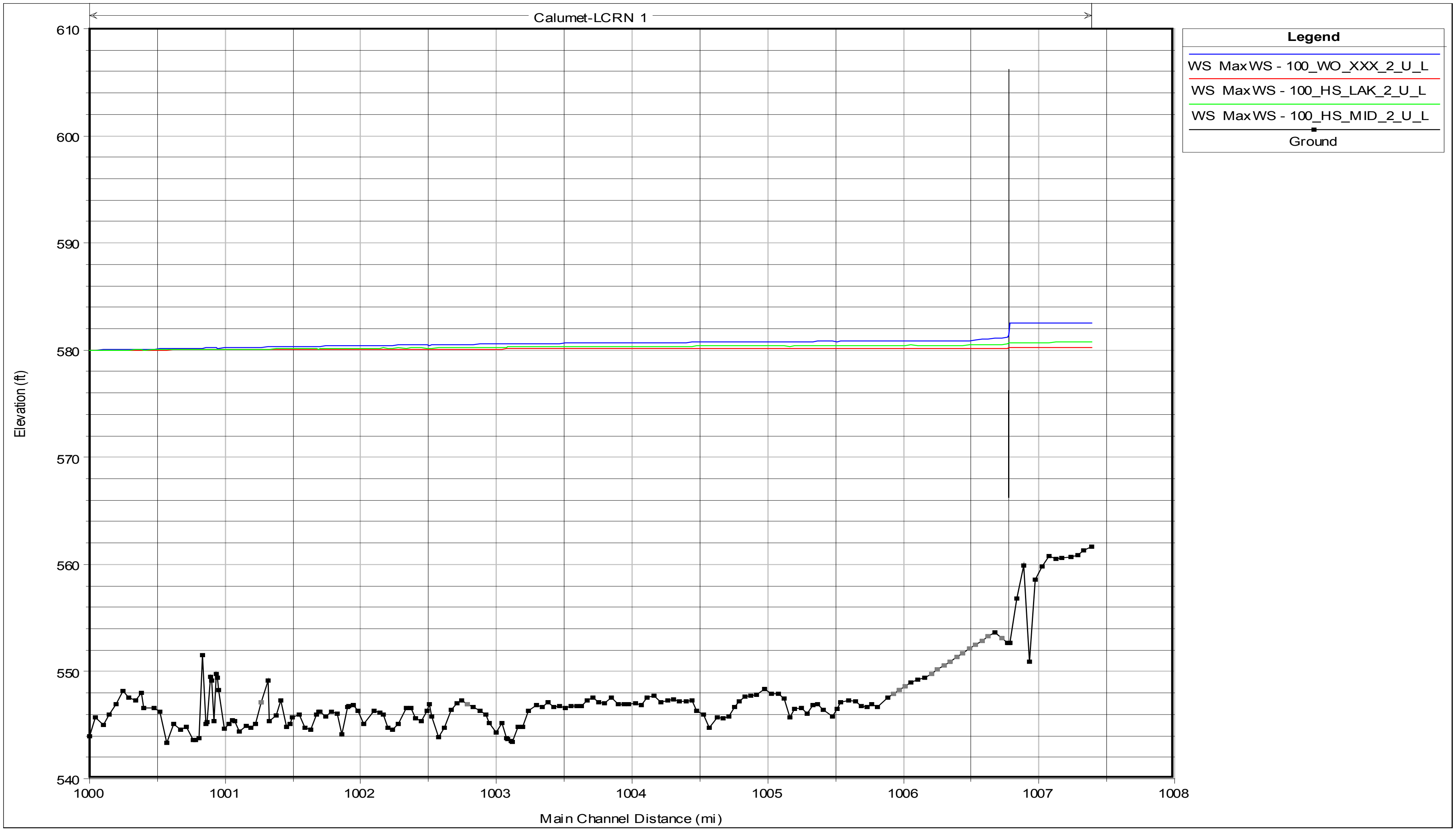

Figure 42 – Comparison of 100 year Maximum Water Levels on the Calumet River upstream of O'Brien Lock and Dam for the Future Condition, Future Condition with Lakefront Hydrologic Separation and Future Condition with Mid-System Hydrologic Separation

ENCLOSURE C

BASEMENT FLOODING

Great Lakes and Mississippi River Interbasin Study: Hydrologic and Hydraulic Impact on Sewer Systems

Prepared for

United States Army Corps of Engineers

July 2013

CH2MHILL®

GREEN METRO PLANNING

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Acronyms and Abbreviations

CAWs	Chicago Area Waterways
CCD	Chicago City Datum
CDS	Calumet Dropshaft
cfs	cubic feet per second
CMAP	Chicago Metropolitan Agency for Planning
CSO	combined sewer overflow
CSSC	Chicago Sanitary and Shipping Canal
CTSM	Chicago Trunk Sewer Model
DCIA	directly connected impervious area
DS	dropshaft
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GLMRIS	Great Lakes and Mississippi River Interbasin Study
H&H	hydrologic and hydraulic
HEC-DSS	Hydrologic Engineering Center Data Storage System
HEC-RAS	Hydrologic Engineering Center River Analysis System
IUHM	Illinois Urban Hydrologic Model
MWRDGC	Metropolitan Water Reclamation District of Greater Chicago
NGVD 29	National Geodetic Vertical Datum of 1929
NAVD 88	North American Vertical Datum of 1998
NBCRPS	North Branch Chicago River Pumping Station
NRCS	Natural Resources Conservation Services
NRGD	Natural Resources Geospatial Data
RAPS	Racine Avenue Pumping Station
RTC	real-time controls
SWMM	Storm Water Management Model
TARP	Tunnel and Reservoir Plan
TNET	Tunnel NETwork
U of I	University of Illinois
UIUC	University of Illinois at Urbana-Champaign
USACE	United States Army Corps of Engineers
WRP	water reclamation plant

SECTION 1

Introduction

1.1 GLMRIS Study Background

The United States Army Corps of Engineers (USACE) is performing the Great Lakes and Mississippi River Interbasin Study (GLMRIS) as a means of evaluating the benefits and costs of various management scenarios for mitigating the risks of invasive species transfer between the Great Lakes and Mississippi River basins. Construction of the Chicago Sanitary and Shipping Canal (CSSC), which was completed in 1900, and the Calumet-Sag Channel, which was completed in 1922, produced a continuous hydraulic connection between these two historically separated basins, opening up the possibility of invasive species transfer between the basins. The USACE has developed two principal river management alternatives to achieve the separation of the two basins (shown schematically in Figure 1-1 at the end of this report).

River management scenarios will influence anticipated levels for the Chicago Area Waterways (CAWs), including the North Branch of the Chicago River, the South Branch of the Chicago River, the Chicago River, Bubbly Creek, CSSC, Calumet River, Little Calumet River, Calumet-Sag Channel, and the North Shore Channel.

1.2 Study Objectives

The objective of this study is to quantify the additional risk of basement and/or street flooding resulting from sewer system backups influenced by increased river levels at the sewer system outlet due to the river management alternatives. Increase in overbank flooding risk is a component of the GLMRIS study; however, overbank flooding risk is not considered in the present analysis of sewer system impacts from modified river management scenarios. This study builds upon existing sewer system models and the development of new sewer system models for nine communities to provide estimates of flood risk increase throughout the system for a range of storm return periods. The quantitative outputs include an estimate of the increase in water level, as well as an indication of whether a river management alternative causes flooding to cross a basement- or street-flooding threshold (discussed below). These model outputs will be used by the USACE to perform an economic analysis of flood damages associated with each alternative.

1.3 Study Area Overview

The study area includes the City of Chicago and nine suburban communities identified by the USACE as a representative subset of communities potentially experiencing increased sewer system flooding risk resulting from river management alternatives. The communities are described in Table 1-1.

TABLE 1-1
Communities Included in GLMRIS Hydrologic and Hydraulic Study

Community	Population	Total Area [square miles]	Adjacent Waterways	System Type
Blue Island	23,463	4.2	Cal-Sag Channel, Calumet Slough	Mostly Combined
Burnham	4,170	1.9	Little Calumet River, Grand Calumet River	Combined
Calumet City	37,042	7.3	Grand Calumet River, Little Calumet River	Combined
Chicago	2,707,120	234.0	Chicago Sanitary and Shipping Canal, Chicago River, North Shore Channel, Bubbly Creek, Little Calumet River	Combined
Dolton	25,614	4.7	Little Calumet River	Mostly Combined
Evanston	74,486	7.8	North Shore Channel	Combined
Forest View	778	1.2	Chicago Sanitary and Shipping Canal	Separate

TABLE 1-1
Communities Included in GLMRIS Hydrologic and Hydraulic Study

Community	Population	Total Area [square miles]	Adjacent Waterways	System Type
Harvey	30,000	6.3	Little Calumet River, Calumet Union Drainage Ditch	Mostly Combined
Palos Hills	17,665	4.3	Cal-Sag Channel	Separate
South Holland	22,030	7.3	Little Calumet River, Thorn Creek, Calumet Union Drainage Ditch	Mostly Separate

Source: Waterways and system types based on review of community sewer atlas information.

SECTION 2

Data Collection and Evaluation

Hydrologic and hydraulic (H&H) modeling requires an abundance of data for characterizing the sewer system, including pipe alignment, depth, and connectivity information, as well as pump sizes and pump curves, weir elevations, and designation of sewer system type. Principal sewer system types are separate sewer systems, which include distinct sanitary and storm sewers, and combined sewer systems, which convey sanitary sewage and storm runoff together in a single pipe system. The modeling team made an effort to obtain this information from all communities represented in the study.

The University of Illinois (U of I) had performed hydrologic modeling of all the combined sewer areas in the Calumet study area as U of I constructed a model of the Calumet Tunnel and Reservoir Plan (TARP) for the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC). The U of I model (U of I, 2010) was incorporated into this study whenever possible. Scanned and georeferenced sewer atlases and a digitized pipe network were also obtained from U of I.

2.1 Sewer System Data

Sewer system maps and atlases, in some cases digitized in geographic information system (GIS), provide the base data for construction of sewer system models. The quality and completeness of sewer system data vary by community. In general, data for combined sewer systems is more complete than data for storm sewers. Table 2-1 provides a summary of the available sewer system information by community.

TABLE 2-1
Sewer System Data Summary

Community Name	Sewer Diameter Shown on Atlas	Sewer Invert Shown on Atlas*	Note
Blue Island	X	-	Inverts are not provided.
Burnham	-	-	Some inverts are labeled on atlas.
Calumet City	X	X	Inverts are given; however, the vertical datum is inconsistent on the atlas.
Chicago	X	X	Data are complete.
Dolton	X	X	Data are mostly complete.
Evanston	X	X	Data are complete.
Forest View	X	X	Data are complete.
Harvey	X	X	Data are mostly complete.
Palos Hills	X	X	Data are generally available, but with some inconsistencies. Sewer connectivity is unclear in many locations
South Holland	X	-	Sewer connectivity is unclear in many locations.

*Sewer invert data are considered complete if sufficient data are present to infer pipe geometry with a high degree of confidence. This does not imply that all inverts are provided, which is generally not the case.

2.1.1 Sewer System Types

The impact of raised waterway levels on basement and street flooding differs by sewer system type. Nearly the entire City of Chicago and many of its suburbs have combined sewer systems that use a single pipe network to convey both sanitary flow and stormwater runoff. The combined system connects to TARP and has overflows to the channels and rivers. Increase in river levels may cause increased basement backups (instances when the head on the combined sewer system exceeds the level inside the building, causing backflow of combined sewage into the home), standing water on streets, and changes in the amount and frequency of combined sewer overflows (CSOs).

Separate sewer systems consist of a storm sewer network and a sanitary sewer network. The storm sewer network handles only stormwater runoff and consists of pipes and ditches that convey stormwater runoff to the CAWs. Changes in river levels may cause increased standing water on streets and ditches. Sanitary sewer network is composed of pipes that generally convey sewerage to MWRDGC interceptors. Although sanitary sewer systems may be affected by changes in river levels due to the existence of MWRDGC interceptor overflows to CAWs, the impact is considered indirect. The sanitary sewer systems are not included in this study because of the following considerations:

1) When modeling sanitary sewer systems, it is critical to have a reasonable estimate of inflow and infiltration (I/I) into the systems, especially for the aged systems like we run into in the Chicago area. Basement backups in sanitary sewer service areas are almost always due to too much I/I in the system. A newly built sanitary sewer system with little I/I rarely has problem.

While storm runoff in combined or storm sewer areas is relatively well understood, there is no rule of thumb for I/I. The amount of I/I can vary a lot from one street to another and from community to community. Without data to reasonably estimate I/I in sanitary sewer communities, it is difficult to reasonably model sanitary sewer systems. Installing flow meters to monitor I/I in these communities would be beyond the scope of the GLWRIS project.

2) Sanitary sewer performance is affected by downstream MWRDGC interceptors. Because MWRDGC interceptors also take flow from communities not modeled in the GLMRIS project, model results for MWRDGC interceptors involve a high degree of uncertainty.

3) The GLMRIS model generally includes sewers 36 inches and larger. Sanitary sewers are generally small in size. Should sanitary sewers be included in the GMRIS model, only a small portion of the sanitary sewers would have been modeled, which would not be representative of the entire sanitary sewer system.

In summary, the hydraulic modeling of sanitary sewer system response to wet-weather inherently involves large degrees of uncertainty, and generally requires extensive metering to reasonably estimate empirical parameters representing inflow and infiltration, which is beyond the scope of this project. In the absence of such monitoring data, it is not possible to characterize whether the conditions of increased MWRD interceptor levels and hydraulic capacity issues in the sanitary sewer system exist, for a given rainfall event, to contribute to increased risk for sanitary sewer models.

2.1.2 Chicago Combined Trunk Sewer Model

The Chicago Trunk Sewer Model (CTSM), which includes all combined sewer pipes 42 inches in diameter and greater and all outfall pipes, was used in the GLMRIS H&H model for the City of Chicago. The model is constructed in the InfoWorks modeling platform, and the model uses the Storm Water Management Model (SWMM) Runoff hydrologic model with subcatchments averaging roughly 20 acres in size. The Chicago trunk sewer model is described further in the Chicago Trunk Sewer Model Protocol (CDM, 2007). Key details regarding the Chicago trunk sewer model include the following:

- MWRDGC interceptor sewers within the City of Chicago, including connecting structures to MWRDGC TARP dropshafts (DSs)
- Simplified, volumetric representation of the existing tunnel volumes using storage nodes:
  - Real-time controls (RTC) close TARP gates when a level of -385.48 ft (NGVD29) is reached in the system. This elevation is roughly 200 feet below ground and represents the condition when the TARP tunnels are mostly full.

  - For future conditions when the TARP reservoirs are online, the sluice gates are left open and all flow is allowed to leave the storage node. This represents an infinite reservoir volume with no conveyance capacity restrictions downstream of the TARP connecting structures. The modeler may also apply alternative boundary conditions to different levels of TARP storage availability at the onset of the storm.

- MWRDGC pumping stations, including the North Branch Chicago River Pumping Station (NBCRPS), Racine Avenue Pumping Station (RAPS), 95th Street Pumping Station, 122nd Street Pumping Station, and Calumet Pumping Station
- City of Chicago Rainblocker inlet restrictors, which limit inflow into the Chicago sewer system; CTSM subcatchments are divided into "restricted" and "unrestricted" subcatchments, with the latter bypassing the inlet restriction curves into the hydraulic network
- The most up-to-date existing conditions model of Chicago available, last updated in mid-2010; the CTSM continues to evolve as Chicago invests in its sewer system

The RTC representation of TARP in the CTSM was modified, as described in Section 3.5.2, to integrate with the TunnelNETwork (TNET) boundary conditions representing TARP.

2.1.3 MWRDGC Calumet Interceptor Model

U of I has developed an EPA-SWMM interceptor model of the Calumet combined sewer system tributary to TARP (Schmidt and Miller, 2010). The Illinois Urban Hydrologic Model (IUHM) was used to simulate runoff from combined areas of the Calumet system. Detailed representations of MWRDGC controls and TARP connecting structures are included in the hydraulic network, including RTC settings to control inflows to TARP.

The majority of communities evaluated in the GLMRIS H&H study are connected to the Calumet interceptor system, which may impact flows in the individual community systems, particularly when TARP is unavailable (i.e. unconstructed, or not available due to utilization of its storage capacity from prior events) . Therefore, the Calumet interceptor system was converted from EPA-SWMM into InfoWorks, allowing for the interceptor sewers to be included in the GLMRIS H&H model. Minor modifications to the network geometry were made to facilitate use of an RTC approach similar to the CTSM.

2.1.4 MWRDGC Combined Sewer Model(s)

The U of I had developed InfoSWMM models of the two subsystems of Dolton: the area tributary to Calumet Dropshaft (CDS)-17, and CDS-51. These models included all pipes in the service areas, as well as the subareas loading to these pipes. The scale of the subareas is smaller than that of most areas included in the GLMRIS model, because of the inclusion of all pipes in the Dolton sewer system. Despite this difference, the U of I Dolton model was considered applicable for the purpose of the GLMRIS study, and the model was imported into InfoWorks for use in the GLMRIS study.

2.1.5 Evanston Combined Sewer Model

In the last two decades, the City of Evanston implemented its relief sewer program, enabling excess runoff that cannot be conveyed by the existing combined sewer system to be conveyed by the new relief sewers. As a result, its existing combined system functions similar to a sanitary sewer system and the majority of wet-weather runoff is conveyed by the storm sewer relief system. Therefore, the current study only includes Evanston's current relief sewer system, and not the formerly combined sanitary sewer system. The XP-SWMM model for Evanston received from the USACE represents its combined sewer system and is therefore not used in the GLMRIS H&H study.

2.2 Community Meetings and Field Investigation

Based upon review of initial sewer system data available from sewer atlases and GIS, a list of questions was developed for each community regarding sewer system geometry and performance. Topics included general drainage patterns, depth and size of existing sewers, and frequency and severity of basement and street flooding associated with the sewer system. A majority of the communities provided additional data for the modeling team based upon field investigation of the sewer assets in question. In several instances, the modeling team met with representatives from the communities to discuss data needs, general sewer system performance, and locations of the most frequent basement and street flooding. Per the City of Chicago modeling protocol (CDM, 2007), the data source was flagged and noted in the model. In instances where the community was unable to resolve sewer system data questions, assumptions were made based upon engineering judgment, and flagged and noted in the model per the protocol.

2.3 Additional Geographic Information System Data

GIS data were used to better understand land use, aquatic features, and the geographic context of drainage systems within the study area. GIS feature classes utilized for this study include the following:

- Topography: 2003 Cook County topographic data, including 2-foot contours
- Land Use: 2005 Chicago Metropolitan Agency for Planning (CMAP) Land Use data; building footprint and edge of road layer where available
- Population: 2000 TIGER census data
- Waterway layer
- CAWs Hydraulic Cross-sections
- Model networks (GIS representation of pipe system, nodes, and subcatchments)

SECTION 3

Model Development

Both hydrologic and hydraulic models were developed to provide a technical basis for quantifying incremental flood risk associated with river management alternatives (see Sections 3.1 and 3.2). Both models were developed in a manner consistent with the Chicago Combined Sewer Model Protocol (CDM, 2007), facilitating comparison of model results across the study area.

Information in subsequent sections summarizes model data developed for the GLMRIS H&H models.

3.1 Hydrologic Model Development

The hydrologic model represents the system's runoff response to rainfall, simulating runoff produced by impervious areas and saturated pervious areas that are loaded into the sewer network. Because peak flow rates and storm timing may contribute to the severity and extent of flooding, hydrologic models are key to the accuracy and usefulness of H&H models. In the GLMRIS H&H evaluation, the river management alternatives do not affect the hydrology of the study area; therefore, the same hydrologic model is applied across all evaluations. Table 3-1 summarizes the overall imperviousness of the communities included in the GLMRIS study.

TABLE 3-1
Community Hydrologic Data Summary

Community	Total Contributing Area (square miles)	Average Percent Impervious[a]	Number of Subcatchments
Blue Island	0.65	49.2%	39
Burnham	0.48	47.9%	15
Calumet City	4.22	61.9%	133
Chicago	190.1	60.2%	14,128[b]
Dolton	3.05	53.4%	1215
Evanston	6.4	44.1 %	207
Forest View	0.11	45.5%	7
Harvey	4.92	48.8%	165
Palos Hills	4.48	48.2%	187
South Holland	5.04	55.0%	179

[a] Average Percent Impervious is given as a percentage of modeled area, excluding non-contributing areas, such as forest preserve and large parks that would lower the overall imperviousness.

[b] Chicago hydrology is generally represented by two overlapping subcatchments to represent Chicago's Rainblocker inlet restrictors, as described in Section 2.1.2.

3.1.1 Subarea Delineation

Subareas are the spatial divisions within a lumped hydrologic model with response characteristics defined by hydrologic parameters (discussed below). Subareas were divided on the basis of the existing sewer network and topography, with flows generated within a subarea simulated as loading to a single node in the sewer network. In general, subareas were divided to produce an average subarea size similar to the CTSM (roughly 20 acres); however, subarea size is also dependent on pipe size and the extent of the hydraulically modeled system.

3.1.2 Hydrologic Parameter Estimates

Hydrologic parameters integrate the effects of land use, drainage network, soils, and topography into the subarea's runoff response; this affects the volume of runoff produced, peak runoff rates, and the timing of the hydrograph. While subarea parameters can be estimated based upon GIS data, parameters such as width and slope have a quasi-physical meaning and are often modified during calibration.

3.1.2.1. Directly Connected Impervious Area

Directly connected impervious area (DCIA) is impervious area that produces runoff which flows into a sewer system. In general, all roadways, most rooftops, and driveways connect into the sewer system and therefore are directly connected. DCIA is the most significant hydrologic model parameter affecting runoff volume, and is therefore a critical model parameter.

GIS layers were not available to directly estimate DCIA based upon component impervious features (e.g., building rooftops, roads, and alleys) for the majority of suburban model areas. The modeling team used a two-tiered approach o relate land-use data to impervious area throughout the study area, with a goal of using the most accurate data available to represent DCIA. First, DCIA was manually digitized within subareas representing the predominant land uses in that community (excluding Chicago), providing a community-level basis for estimating the impervious area percentage for this land use. In most of the modeled GLMRIS suburban communities, single-family residential development (code 1110) is the most prevalent land-use category. Table 3-2 summarizes the manual impervious estimate for predominant land-use category by community.

TABLE 3-2
Impervious Percentage by Community for Key Land Uses

Community Name	Land Use Description	Percent Impervious
Blue Island	1110 RES/SF	41.3%
Burnham	4110 VAC FOR/GRASS	4.3%
Burnham	1110 RES/SF	42.1%
Calumet City	3300 OPENSP CONS	7.0%
Calumet City	1110 RES/SF	60.4%
Evanston	1110 RES/SF	38.0 %
Dolton	1110 RES/SF	49%
Forest View	1110 RES/SF	41.6%
Harvey	111110 RES/SF	40.6%
Palos Hills	1110 RES/SF	41.0%
South Holland	1110 RES/SF	51.1%
South Holland	1440 INDUST PK	73.2%

Subsequently, general land use impervious percentages were estimated for land-use categories comprising a smaller percentage of a community's drainage area. Average imperviousness for specific land-use categories was estimated by comparing against the impervious layer which exists within Chicago, to define an average imperviousness for each land use. When a localized land-use imperviousness estimate was not available, the generalized estimates from Table 3-3 were applied.

TABLE 3-3
General Impervious Percentage by Land Use in Chicago

Land Use Description	Percent Impervious	Land Use Description	Percent Impervious
1110 RES/SF	49%	1511 INTERSTATE/TOLL	62%
1120 RES/FARM	60%	1512 OTHER ROADWY	72%
1130 RES/MF	62%	1520 OTH LINEAR TRAN	77%
1140 RES/MOBILE HM	28%	1530 AIR TRANSPORT	48%
1211 MALL	95%	1540 INDEP AUTO PRK	91%
1212 RETAIL CNTR	86%	1550 COMMUNICATION	30%
1221 OFFICE CMPS	61%	1560 UTILITIES/WASTE	45%
1222 SINGL OFFICE	85%	2100 CROP/GRAIN/GRAZ	10%
1231 URB MX W/PRKNG	81%	2200 NRSRY/GRNHS/ORC	2%
1232 URB MX NO PRKNG	86%	3100 OPENSP REC	24%
1240 CULT/ENT	74%	3200 GOLF COURSE	6%
1250 HOTEL/MOTEL	72%	3300 OPENSP CONS	4%
1310 MEDICAL	69%	3500 OPENSP LINEAR	39%
1320 EDUCATION	61%	3600 OPENSP OTHER	83%
1330 GOVT	76%	4110 VAC FOR/GRASS	10%
1340 PRISON	63%	4120 WETLAND	4%
1350 RELIGOUS	69%	4210 CONST RES	70%
1360 CEMETERY	6%	4220 CONST NONRES	65%
1370 INST/OTHER	57%	4300 OTHER VACANT	44%
1410 MINERAL EXT	47%	5100 RIVERS/CANALS	4%
1420 MANUF/PROC	78%	5200 LAKE/RES/LAGOON	2%
1430 WAREH/DIST/WHOL	74%	5300 LAKE MICHIGAN	0%
1440 INDUST PK	68%		

3.1.2.2. Soil Infiltration Parameters

The Horton Model was utilized to represent runoff infiltration into soil as a function of soil characteristics and preceding rainfall.

Geospatial soils data are available for the majority of the study area outside Chicago, including data from the Natural Resources Conservation Services (NRCS) and the Illinois Natural Resources Geospatial Data (NRGD). Methods exist for associating soil loss parameters from such data. However, because the study area is developed and because soils have generally been significantly disturbed and/or compacted during development, the soils infiltration properties may not correlate strongly with the soil mapping. For this reason, uniform soil infiltration parameters were applied across the study area for newly developed models, consistent with the approach utilized for the Chicago combined trunk sewer model. Table 3-4 summarizes the modeled soil infiltration parameters.

TABLE 3-4
Horton Soil Infiltration Coefficients

Horton Soil Infiltration Coefficient	Infiltration Rate
Initial	2.00 in/hr
Limiting	0.10 in/hr
Decay	2.16 (1/hr)

3.1.2.3. Subarea Width

The subarea width relates to the subarea time of concentration, with larger widths having smaller associated subarea lengths that produce "peakier" runoff hydrographs. The width is thus a parameter that attempts to represent the aggregate impact of a diversity of drainage routes within a subarea, including runoff from rooftops, along gutters, and within unmodeled sewers. In general, the InfoWorks default width was used, equaling the radius of a circle having the area of the subarea. However, in cases where the length of the subcatchment was significantly greater than the width of the subcatchment (i.e. length to width ratio greater than 5), the manually estimated width of the subcatchment was used, resulting in a greater length and a stretched, lower peaked hydrograph reflecting routing time within the hydrologic subcatchment.

3.1.2.4. Subarea Slope

The subarea slope is an additional runoff parameter with a physical interpretation within the idealized SWMM runoff catchment that, in reality, aggregates a range of impacts of surface slope occurring within a subarea. Because the study area is generally flat, a uniform subarea slope estimate of 0.05 percent was utilized throughout the model, consistent with the CTSM.

3.1.2.5. Population Estimate

Dry-weather flow produced by residential, commercial, and industrial development is generally a small percentage (less than 10 percent) of combined system hydraulic capacity. Trade flows associated with industry can vary widely based upon industrial processes, and the flows generally require metering to estimate. In the absence of monitoring data, a constant value of 160 gallons per capita per day was used to estimate dry-weather inflows, which is an intermediate value based upon the CTSM. Year 2000 census data were used to estimate population.

3.1.3 Rainfall

Design rainfall events for eight recurrence intervals and three storm durations were analyzed as part of this study. Rainfall depths from Bulletin 71 (Huff and Angel, 1992) were used for this study, consistent with the rainfall applied by the USACE for the waterway analysis. Table 3-5 summarizes the rainfall data utilized in the study.

TABLE 3-5
Bulletin 71 Rainfall Depths

Annual Exceedance Probability	3-Hour	12-Hour	24-Hour
99% (1-yr)	1.60	2.18	2.51
50% (2-yr)	1.94	2.64	3.04
20% (5-yr)	2.43	3.31	3.8
10% (10-yr)	2.86	3.89	4.47
4% (25-yr)	3.53	4.79	5.51
2% (50-yr)	4.14	5.62	6.46
1% (100-yr)	4.85	6.59	7.58

TABLE 3-5
Bulletin 71 Rainfall Depths

Annual Exceedance Probability	3-Hour	12-Hour	24-Hour
0.2% (500-yr)	5.00	7.28	8.64

The rainfall depth was distributed according to Huff quartile distributions based on storm duration, as described in Bulletin 71. Areal reduction factors, which are utilized to represent the reduced probability of uniform rainfall across a large area, were considered for application in GLMRIS H&H models. Areal reduction factors were not applied for any of the newly developed models, because the total area of each community is less than 10 square miles. The CTSM does include areal reduction factors, which were retained for this analysis, based upon the size of distinct Chicago drainage hydraulic subsystems.

3.2 Hydraulic Model Development

The hydraulic model comprises the sewer conduits, connecting and outfall structures, pumps, gates, and weirs that convey and control flows throughout the system. Stormwater generated from the hydrologic model is loaded to the hydraulic model, which balances energy, momentum and continuity equations to route flow to an outlet. Table 3-6 summarizes the hydraulic elements included in the GLMRIS study by community.

TABLE 3-6
Community Sewer Summary

Community	Less than 42" Diameter Modeled Pipe Length (mi)	Greater than or Equal to 42" Diameter Modeled Pipe Length (mi)	Number of Nodes	Number of Links
Blue Island	3.0	0.6	94	87
Burnham	1.3	0.3	39	34
Calumet City	7.9	4.9	236	243
Chicago	391.8	619.8	30,266	32,649
Dolton	39.5	4.1	1,138	1,131
Evanston	9.26	19.0	622	612
Forest View	0.6	0.0	21	20
Harvey	9.6	11.8	374	374
Palos Hills	11.2	8.6	756	717
South Holland	11.1	6.8	440	368

3.2.1 Pipe Network and Geometry

The pipe network for each modeled community was defined based upon sewer atlas data that was augmented by record drawings and/or community information. Key pipe attributes include upstream and downstream invert elevations, diameter, and length. Pipe invert elevations are frequently not available, in which case linear inference or extrapolation was used to provide an estimate of the invert elevation (flagged per the modeling protocol).

3.2.1.1. Modeled Pipes

The Chicago Trunk Sewer Model protocols (CDM, 2007) prescribe inclusion of all pipes 42 inches in diameter and greater, as well as smaller pipes where hydraulically significant, and all pipes leading to CSOs. The CTSM was imported in totality into the GLMRIS study model.

In the modeled suburban communities, the sewer systems are significantly smaller because they serve much smaller areas. For this reason, the threshold for hydraulic modeling was lowered to include pipes 30 inches in diameter and greater (and all sewers draining to a CSO location).

3.2.1.2. MWRDGC Interceptors

The MWRDGC interceptor system collects flows from the upstream collection systems, conveying them to the water reclamation plant (WRP) for treatment. The MWRDGC interceptor system is an integral component of the hydraulic system of Chicago and its surrounding communities. The MWRDGC interceptor's behavior is a key factor influencing both CSO timing and volume, as well as basement flood risk in the overall collection system.

The CTSM includes the MWRDGC intercepting sewers within the boundaries of Chicago. For the interceptors conveying flow to the Stickney WRP and the North Side WRP, the modeled interceptor representation is substantially complete in the CTSM. However, the Calumet interceptor system has a relatively small portion within Chicago. Seven of the nine suburban communities included in the GLMRIS model analysis connect to the Calumet interceptor system. Based upon the importance of the Calumet interceptor to the hydraulic response of these community systems, it was determined that the Calumet interceptor should be included in the hydraulic model for the GLMRIS system.

U of I has developed a hydraulic model of the Calumet interceptor system (U of I, 2010). The model was developed in the EPA-SWMM hydraulic modeling platform and was converted to the InfoWorks CS platform by U of I. Review of the geometry data and controlling structures (sluice gates, tide gates, and weirs) was performed, and it was determined that the Calumet interceptor model data were of sufficient detail and accuracy for use in the GLMRIS study. The GLMRIS modeling team identified several model issues introduced during the U of I model conversion (mostly around hydraulic structures and tide gates). Because the U of I interceptor model reflects the entirety of the Calumet interceptor, some overlaps exist with the CTSM. In general, the Chicago sections of the Calumet interceptor model were retained, because they included slightly more detail and integrated more completely with the trunk sewers of the Chicago system.

3.2.1.3. Roughness Coefficients

The pipe roughness coefficient (Manning's n value) directly affects a pipe's conveyance capacity. Factors influencing pipe roughness include pipe age, material, and condition—increasing roughness decreases pipe capacity. Pipe age and material information was generally not available for the modeled communities. A roughness coefficient of 0.015 was the default used for this study (consistent with the Chicago modeling protocols). However, in the following instances, a slightly modified roughness coefficient was assumed:

- **For existing models incorporated into the GLMRIS study.** The roughness values of the existing model were retained. This applies to the Dolton models imported from the U of I study.
- **For local sewers in CTSM.** As the CTSM was developed and refined (external to this study), the Chicago modeling team decided to use smaller roughness coefficients for local sewers to account for lowered minor losses in these pipes. Therefore, within Chicago a roughness coefficient of 0.013 was used for pipes with diameters less than 24 inches, and 0.014 was used for pipes with diameters between 24 and 36 inches (inclusive).
- **For recently built Evanston relief sewers.** A Manning's roughness coefficient of 0.013 was used for tunnels, and 0.014 was used for all other relief sewers.

3.2.1.4. Minor Headloss Parameters

Minor headlosses at junction structures and manholes were incorporated by using a relatively conservative Manning's n values for pipes, consistent with the Chicago modeling protocols (CDM, 2007).

3.2.1.5. Inlets

Stormwater enters the hydraulic network through inlets or catch basins, which are generally collection structures with an open grate. Based upon inspection of the sewer atlases, the density of sewer system inlets varies greatly within and across communities. In Chicago, the Rainblocker inlet restrictors limit the peak rate of inflow into the system based upon the distribution of orifice and vortex restrictors. In suburban communities it was assumed that inlets were not restrictive (in comparison with the sewer itself), and flow was not restricted through the inlets into the system.

3.2.2 Hydraulic Structures

Hydraulic structures are active (pumps, gates) or passive (weirs) structures within the system that control the flow of water, providing operators with some ability to direct flow within the system. In general, community sewer systems are gravity-based with relatively few controls. The MWRDGC interceptor system is actively controlled, primarily through sluice gates that control inflows into TARP, with pumps outside and within the treatment works controlling interceptor outflow.

3.2.2.1. Pumps

The CTSM includes several large pumping stations owned by the MWRDGC, including the 125th Street Pumping Station, 122nd Street Pumping Station, Racine Avenue Pumping Station (RAPS), North Branch of Chicago River Pumping Station (NBCRPS), and 95th Street Pumping Station. Pumping strategies for these facilities were defined in the construction of the CTSM, and strategies are documented on the notes fields of the pumps within the model.

The other modeled communities include only two sewer pumping stations:

- The Village of Burnham has a pumping station at the outfall immediately downstream of the connection to CDS-21. Based on communication with the Burnham Public Works Director, the pump is in use, although no information on its capacity and frequency of use is available. The model is set up such that, when TARP capacity is available at dropshaft (DS) -21, the flow goes to TARP, with any excess flow pumped to the Grand Calumet River through this pump. This pump hydraulically isolates the west Burnham system from any impacts related to river water-level rise.
- Calumet City also includes a pumping station for dry-weather flow into the MWRDGC interceptor system, located near the intersection of Burnham Street and State Street. However, the community did not provide information regarding this pumping station. The operational settings of this pumping station were included in the U of I SWMM model and were retained in this study.

3.2.2.2. Sluice Gates

Sluice gates enable operators to limit or close specific conveyance paths, forcing flows to alternate outlets. Sluice gates in the GLMRIS models are associated with the connecting structures to the MWRDGC TARP system. The data source for all sluice gates included in the CTSM is documented in the notes section of the model (The drawing date is usually referenced in MWRDGC TARP construction drawings.). Section 3.6.2 provides additional information on how the sluice gates are controlled in the model.

3.2.2.3. Weirs

In general, modeled weirs represent structures that keep dry-weather flow in the interceptor system, and allow wet-weather flow to overflow to the CAWs or to TARP. Weirs are included in the model where indicated based upon GIS, construction record drawings, or other data sources.

Dummy weirs were included in specific locations in the model where review of topographic data indicated that overland flow would commence above a certain level of ponding, preventing significant further increase in water level. The default aboveground storage within InfoWorks, represented by an inverted-cone surface-flow storage volume, would continue to rise, over-predicting peak hydraulic grade. This is a simplified representation of a complex process; to fully simulate the process would require a two-dimensional model, which is beyond the scope of the GLMRIS study.

3.3 Dry-weather Flow

As explained in Section 3.1.2.5, dry-weather flow is generally comprised of sanitary flows, industrial ("trade") flows, and groundwater infiltration into the sewer system. In the CTSM, influent to MWRDGC WRPs and metered calibration data were used to assign sanitary and trade flows to account for observed flow patterns during periods without rainfall.

Meter data were not available for calibration of dry-weather flow in the modeled communities other than Chicago. In combined sewer sections of the system, dry-weather flow was assigned based upon the estimated population. An estimate of 160 gallons per capita per day was assigned.

3.4 Flooded Basement Storage

During heavy storm events, basements in combined sewer areas may be flooded due to surcharged water levels in the sewer system that result in backups. Flooded basements provide storage of stormwater that in turn affects water levels in sewer systems. However, modeling the impact of basement storage on sewer system water levels involves making a number of assumptions with substantial uncertainties. For example, basement floor depths and areas may vary significantly from one home to another. When the basement of one home is flooded with 2 feet of water, another home on the same street may not experience flooding at all because it has a different basement depth and ground elevation. Given the substantial uncertainties, it was decided that basement storages would not be modeled in this study. Without representing basement storage in the hydraulic model, predicted maximum water levels may be slightly higher than are observed in reality. This simplification is consistent with typical modeling approaches for representing flood potential at this scale; it is also a conservative assumption.

3.5 Boundary Conditions

Boundary conditions represent processes not explicitly represented within the GLMRIS H&H models that influence the performance of the modeled GLMRIS H&H system. The GLMRIS H&H evaluations are in effect sensitivity analyses to boundary conditions, because the study focuses on the additional flood risk associated with modified river level conditions. Therefore, boundary conditions are a critical input to GLMRIS H&H models.

3.5.1 System Inflows

The modeled communities' sewer systems do not receive inflows from adjacent communities. However, the MWRDGC Calumet interceptor system, to which the southern communities all contribute, does receive inflows from communities not included in the GLMRIS H&H study. The U of I TARP analysis used the IUHM model to produce inflows into the modeled interceptor and TARP systems. Because some IUHM basins were also modeled hydraulically for this study, it was possible to compare the results of these two modeling approaches. Hydrographs produced by IUHM were very similar to hydrographs produced by the GLMRIS H&H model for longer-duration storm events (12 hours or more). However, IUHM may significantly overpredict flow hydrographs for the 3-hour-duration, 2-year storm event when compared to the H&H model (see discussion in Section 4.1.2). The IUHM model does not include hydraulic restrictions in the modeled basins, which limit the maximum discharge through a sewer section when the upstream hydraulic grade line is surcharged to ground level.

Based on review of the IUHM results, hydrographs were loaded from IUHM into the sewer system model, and peak flow entering the interceptor system was limited based upon the size of the pipe discharging from the modeled basin. Table 3-7 summarizes IUHM basins loaded into the sewer system and limited pipe size for the basin.

TABLE 3-7
Inflow Loading from Illinois Urban Hydrologic Model for Areas Outside the GLMRIS Hydrologic and Hydraulic Study

IUHM Basin	Loading Node	Area (acres)	Representative Sewer Diameter (in)

TABLE 3-7
Inflow Loading from Illinois Urban Hydrologic Model for Areas Outside the GLMRIS Hydrologic and Hydraulic Study

IUHM Basin	Loading Node	Area (acres)	Representative Sewer Diameter (in)
CDS-10-2	JCT-832	33.6	16.2[a]
CDS-10-3	JCT-426	45.1	18.96 [a]
CDS-11-2	JCT-148	472.6	61.08 [a]
CDS-15-1-1	JCT-844	226.7	42
CDS-15-1-2	CDS15_TG2US	107.2	48
CDS-15-1-3	JCT-236	128.8	30
CDS-15-1-4	JCT-238	13	9.96 [a]
CDS-39-1	JCT-402	483	54
CDS-4	JCT-338	43.3	18
CDS-42-1	JCT-222	611.2	84
CDS-45-1	JCT-598	335.5	48
CDS-5	JCT-396	230.5	30
CDS-55-1	CDS55_170TH_CS	1721.5	96
CDS-57	JCT-868	308.1	54
CDS-6	JCT-494	735.2	54
CDS-7	JCT-736	538.4	60
CDS-9	JCT-420	486.7	60
CDS-Spaulding	Not included	1798.1	n/a[b]

a: In some instances, a single sewer does not exit the IUHM basin, and so a hydraulically equivalent single pipe diameter was calculated limit inflow into the GLMRIS sewer network.

b: CDS-Spaulding basin loads directly to an outfall in the U of I interceptor model, and so has no effected on the modeled GLMRIS system.

The inflows into the system influence the rate at which the Calumet interceptor system fills up, with excess flows conveyed either to the TARP, when available, or to the river. Therefore, the inflow boundary condition influences the timing of the TARP boundary condition effect on system performance.

3.5.2 TARP Representation

The MWRDGC TARP system receives overflows from combined sewer communities in Cook County. Inflows into the system are controlled by sluice gates that control flow to the dropshafts, although numerous dropshafts are not gated.

The USACE performed TARP simulations using a dynamic TNET model for the range of storm events evaluated in the GLMRIS H&H study. The following TARP conditions were considered:

- Baseline Conditions: Includes tunnel storage, tunnel conveyance capacity, and the storage volumes of the Thornton Reservoir and McCook Stage-1. Per guidance from the USACE, the scenarios referred to as “existing conditions” represent the state of TARP in the year 2017.
- Future Conditions: Includes tunnel storage, tunnel conveyance capacity, and the ultimate volume of the McCook and Thornton reservoirs. Per guidance from the USACE, the scenarios referred to as “future conditions” represent the state of TARP in the year 2029.

CH2M HILL requested level output from the TNET model at numerous locations throughout both the Calumet and Mainstream TARP systems. The requested output locations were used to represent hydraulic levels in specific reaches of TARP, which were applied as level boundary conditions to specified outfall nodes in the modeled system. All modeled sluice gates representing control gates to TARP along a given reach were linked to the boundary node, and sluice gates were closed when the level at the boundary node reached 549.48 feet NGVD29, indicating that TARP is full in that part of the system. Table 3-8 summarizes the river reaches along which TARP connections were assigned to the representative boundary node.

TABLE 3-8
TARP Level Hydrographs Applied to GLMRIS H&H Models

System	REACH	Representative Dropshaft
Mainstream	Chicago Sanitary and Ship Canal - US	DS-M19
Mainstream	Chicago Sanitary and Ship Canal - DS	DS-M09
Mainstream	Bubbly Creek	DS-M30
Mainstream	South Branch Chicago River	DS-M49
Mainstream	Chicago River	DS-M55
Mainstream	North Branch of Chicago River - US	DS-M86
Mainstream	North Branch of Chicago River - DS	DS-M73
Mainstream	North Branch of Chicago River - Wild	DS-N02
Mainstream	North Shore Channel	DS-M100
Calumet	140th Street Leg	CDS-15-2
Calumet	Lower Calumet River - US	CDS-52
Calumet	Lower Calumet River - DS	CDS-43
Calumet	Calumet-Sag Channel	CDS-10
Calumet	Calumet City	CDS-22
Calumet	Torrence Avenue	CDS-26
Calumet	Indiana Avenue	CDS-47
Calumet	Crawford Avenue Tunnel	CDS-10

The USACE ran the TNET TARP models to simulate the 2017 and 2029 conditions, assuming the existing conditions waterway configuration. These TARP results were applied to both existing conditions and alternative conditions model runs. Because the Calumet TARP system is expected to be identical in 2017 and 2029, the USACE only provided 2029 TNET output, which was applied to both conditions.

3.5.3 Waterway Representation

The CAWS and associated tributaries will be influenced by river management alternatives considered in the GLMRIS study. Increased water levels in these waterways, which are the receiving system for stormwater and CSO when TARP is unavailable, will affect sewer system performance, and will potentially contribute to increased risk of basement and street flooding.

The USACE used Hydrologic Engineering Center River Analysis System (HEC-RAS) to model the CAWs and associated tributaries, resulting in level hydrographs representing river stage for each storm event and river management alternative considered. CH2M HILL assigned a nearby HEC-RAS station to each outfall in the GLMRIS H&H model, and stage hydrographs were exported by the USACE for each location into a Hydrologic Engineering Center Data Storage System (HEC-DSS) database. Appendix A summarizes the table associating HEC-RAS stationing with modeled outfalls.

The upper reaches of Calumet Union Drainage Ditch are not affected by changes in downstream water levels. The existing conditions waterway levels were applied for all simulations for outfalls along this reach of Calumet Union Drainage Ditch. The upper reaches of the North Branch of the Chicago River are not affected by the river management alternatives, because this section is upstream of a dam. Free outfalls were assumed along this stretch of the North Branch of the Chicago River, because its outfalls are insensitive to river management alternatives.

3.5.4 Water Reclamation Plant Capacity

The MWRDGC North Side, Stickney, and Calumet WRP each treat sewer flows, ramping up from typical DWF treatment to plant maximum capacity during wet-weather events. The WRP capacity is generally less than the surcharged interceptor conveyance capacity, and therefore restricts the system outlet at these points. A flow-limiting orifice was used to limit discharge from the system based upon plant maximum capacity. Table 3-9 summarizes the outlet capacity modeled for each WRP.

TABLE 3-9
Modeled Maximum Water Reclamation Plant Capacity

WRP	Modeled Maximum Capacity (cubic feet per second)
North Side	366.3
Stickney	1583.6
Calumet	379.1

3.6 Datum Conversions

Elevation data were provided from a range of municipality data sources, including GIS and sewer atlases, as well as from the USACE TNET TARP model and HEC-RAS waterway models. The elevation datum of the input data sources was tracked throughout the project, with all model data converted to CCD. The following datum conversions were used:

- National Geodetic Vertical Datum of 1929 (NGVD 29) = CCD + 579.48
- North American Vertical Datum of 1998 (NAVD 88) = CCD + 579.18

The vertical datum was not always clearly defined on available data sources, nor, in some cases, could it be confirmed by community representatives. Field measurements of the depth to the sewer invert offset from ground elevation was performed for selected locations in areas with significant uncertainty regarding sewer invert elevation. Engineering judgment and comparison with other known datums was used, where necessary, to define an assumed vertical datum based upon best available information. Table 3-10 summarizes vertical datum information for communities included in the GMLRIS study.

TABLE 3-10
Datum Summary for Study Data Sources

Data Source	Datum	Comments
Blue Island Field Measurements	NAVD 88	Offset measurements from ground
Burnham Sewer Atlas	Unknown but in range of CCD	Values too high to be CCD; Atlas inverts reduced by ~16.9 ft to provide reasonable cover
Burnham Field Measurements	NAVD 88	Offset measurements from ground
Calumet City Sewer Atlas Sheets 6 and 7	Unknown but in range of CCD	Values range from 15 to 17 ft higher than Cook County topography estimates
Calumet City Sewer Atlas Sheet 12	Unknown but in range of CCD	Values range from 15 to 20 ft higher than Cook County topography estimates

TABLE 3-10
Datum Summary for Study Data Sources

Data Source	Datum	Comments
Calumet City Sewer Atlas Sheet 17	Assumed NGVD 29	Not documented, but within 0 to 1 ft of Cook County topography estimates
City of Chicago Trunk Sewer Model	CCD	
Dolton Sewer Atlases	NGVD 29	Noted on first sheet of Atlas
Dolton CDS-17 and CDS-51 U of I InfoSWMM Model	NGVD 29	
Harvey Sewer Atlases	NVGD 29	Not documented on the atlas, but NGVD 29 is consistent with Cook County topography
Forest View Sewer Atlases	Non-standard	Datum of roughly 578.86' = 0 CCD used on atlas according to Village Engineer
GIS Data Provided by Palos Hills	NAVD 88	NAVD88
South Holland Field Measurements	NAVD 88	Offset measurements from ground
TNET TARP Model Results	NGVD 29	
UIUC Calumet Interceptor Model	CCD	
HEC-RAS Waterway Model Stage Results	NGVD 29	
2003 Cook County Topographic Data	NAVD 88	

SECTION 4

Modeling Analysis

4.1 Calibration

H&H models are developed to represent key processes describing a system's runoff response to rainfall, and the routing of these flows through the drainage system. The ability of the model to serve as a useful tool for evaluation of potential system modifications depends on the degree to which these processes are represented accurately in the model. This is in turn heavily dependent on the quality of baseline data for model construction. In addition to simulation of key physical processes, a model's accuracy may be affected by uncertainty from external factors, which for the GLMRIS modeled systems is most likely to be human-controlled mechanisms such as TARP gates, locks at Lockport, and potentially the operation of large pumping stations like RAPS or the NBCRPS. A calibration effort involves comparison of modeled simulation results to monitored results, and modification of model parameters (within reasonable ranges) to better represent the monitored system values.

4.1.1 Calibration Data Sources

The CTSM, which represents a significant majority of the overall modeled area within the GLMRIS H&H study, was calibrated based upon monitoring data collected at approximately 50 locations between 2007 and 2009. Comparison of modeled and monitored data generally showed good correlation of peak flows and total runoff volume, although with considerable variation throughout the City and varying by storm events. Nevertheless, based on reported calibration efforts (CH2M HILL, 2008) the CTSM is considered a reasonably calibrated model within the range of storm events to which the model was calibrated (roughly between 6-month to 25-year recurrence interval). Higher-intensity storm events may result in significant overland flow and other processes that are less significant for smaller events.

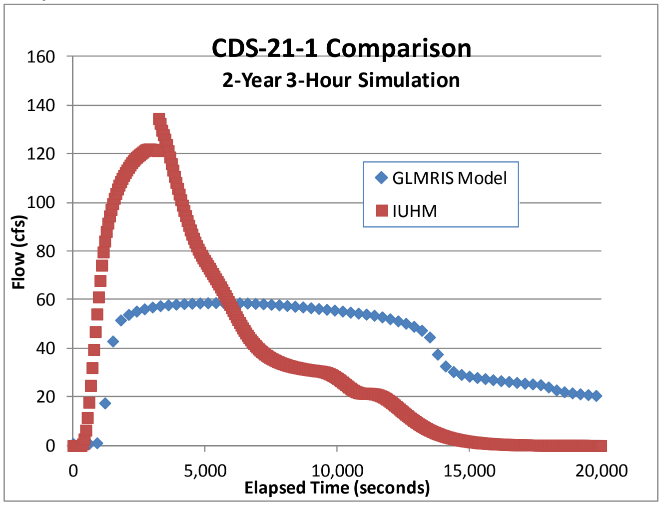
No monitored data existed within the other modeled community areas. However, IUHM models were previously developed for combined sewer areas of the Calumet service area. The IUHM models for CDS-51 and CDS-17, both serving the community of Dolton, were previously compared to a detailed InfoSWMM hydraulic model of Dolton CDS-17 and CDS-15 basins(U of I 2010- Report 6), demonstrating the ability to generally predict timing, shape and peak of the detailed model results. The IUHM model was not considered a calibration data source that would warrant modification of model parameters to more closely match storm peaks and volumes; however, large differences between these two models would indicate model parameter issues within the GLMRIS models.

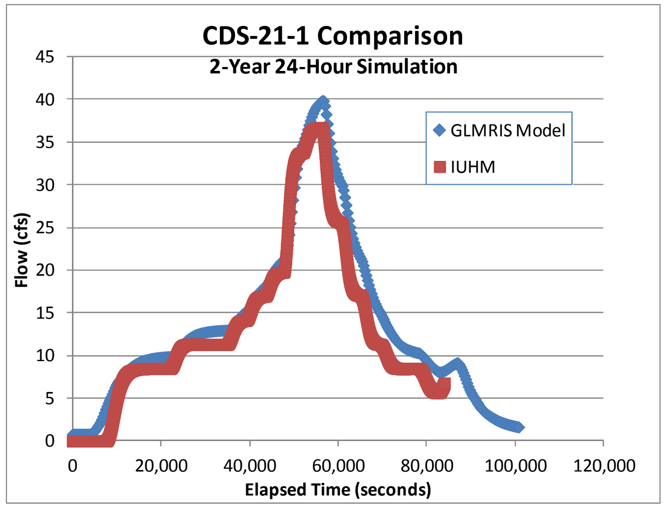
4.1.2 GLMRIS H&H Comparison to IUHM Models

The model results from the GLMRIS suburban model were compared to IUHM model results at several locations where the service areas overlapped. Comparisons were performed for the 2-year, 3-hour simulation, as well as the 2-year, 24-hour simulation. The IUHM model produces and routes flows to the point just upstream of the connecting structure to the TARP system; therefore, a similar comparison point was selected from the CTSM. The flow comparison for the CDS-21-1 tributary area in Burnham is representative of the general trend that was observed (Figure 4-1). The flow hydrographs demonstrate a close correlation for the longer-duration event; however, the peak flow delivered to the system is significantly higher for the IUHM model for the shorter-duration event. The close correlation for the 24-hour event demonstrates that the GLMRIS models show good agreement with other modeled predictions for this longer-duration storm event. During the 3-hour simulation event, hydraulic restrictions within the GLMRIS network limit the peak flows that can be conveyed to the downstream system. The system may surcharge to ground level, but it can pass no additional flow downstream. The IUHM model, however, does not include this hydraulic limitation, and it may be more generally applicable for longer-duration events where the rainfall is of lower peak intensity. The hydraulic limitations of real-world sewer systems suggest that the GLMRIS model may provide a more realistic representation of flow routing during higher-intensity, short-duration events.

FIGURE 4-1

Comparison of GLMRIS Model Results to IUHM Model Results for CDS-21-1 Service Area





4.1.3 Assessment of Calibration Considerations for GLMRIS

The CTSM, comprising the majority of the GLMRIS modeled study area, was reasonably calibrated with 50 flow meters installed between 2007 and 2009. Flow monitoring and model calibration were also performed before 2007 for several individual study areas within Chicago. The runoff parameters adopted in the CTSM were a result of these flow monitoring and model calibration activities. The suburban communities, although without flow metering data, have similar land features as Chicago. Therefore, runoff parameters and approach used in the Chicago model can be applied to these communities with a reasonable level of confidence. The peak runoff rates from subareas in suburban communities are also checked with other methods, such as Rational Method and IUHM, to ensure they are within commonly accepted range.

4.2 Simulation Definition

The USACE (USACE, 2012) defined a subset of simulations conditions to quantify additional flood risks associated with sewer systems affected by raised downstream water levels. The combination of storm frequency (8 frequencies) and duration (1 critical duration), assumed TARP condition (2 TARP conditions), and river management alternative (3 river management alternatives) resulted in 48 unique scenarios for evaluation.

4.2.1 Return Period and Duration

The 24-hour storm was defined as the critical storm for the GLMRIS study area, as further described in Section 4.3 below. The 24-hour duration storm event was modeled for the 1, 0.5, 0.2, 0.1, 0.025, 0.02, 0.01, and 0.002 annual probability rainfall events, corresponding to a return period (in years) that is the reciprocal of the annual probability.

4.2.2 TARP Condition

The impact of increased waterway levels on affected sewer systems is influenced by the availability of the TARP system to receive overflows. Two TARP conditions were chosen by the USACE (USACE, 2012) for evaluation, corresponding to the planned TARP storage and conveyance in the year 2017 (all tunnels complete, and the Thornton reservoir in the Calumet system and McCook Stage-1 for the Main Stream TARP complete), and the year 2029 (McCook reservoir for Mainstream TARP complete).

4.2.3 Alternative Condition

The USACE is evaluating three separation river management alternatives. Two river management alternatives involve hydraulic separation—a Lake-side separation alternative and a mid-system alternative. In addition, a non-hydrologic separation alternative will be evaluated by the USACE, consisting of a nonphysical barrier. This nonphysical separation alternative is not expected to affect CAWs water levels; therefore, it was not included in this study.

4.2.4 Additional Assumptions

The USACE will evaluate some alternatives that include a mitigation component, which provides compensatory storage to offset any proposed level increase associated with the river management alternative. Because these alternatives will result in no rise of the CAWs system, results for mitigated alternatives will be comparable to "without project" alternatives, and are therefore not modeled.

4.2.5 Nomenclature

Modeled scenarios are expressed by the unique identifier code AAA_BB_CCC_D_E, where:

- AAA=flood return period (001, 002, 005, 010, 025, 050, 100, 500)
- BB=separation methods (HS=hydro separation, TS=other technology based separation)
- CCC=location of the separation point (XXX=no project, MID=mid-system, LAK=lakefront)
- D=TARP Condition (1=2017 condition, 2=2029 condition)
- E=mitigation component (U=unmitigated, M=mitigated). Because all evaluations discussed in this report are unmitigated, this designator is omitted.

As an example, the designator "010_HS_MID_1" represents the 10-year return period mid-system hydraulic separation alternative with 2017 TARP assumptions.

4.3 Critical Duration Analysis

The storm duration causing the greatest additional area to be at flooding risk is considered critical for a given annual probability. The effect of any river intervention will vary throughout the system with differing degrees of impact. Based on discussion with the USACE, the critical duration will not be defined on a community-by-community basis, but rather will be defined for the overall model area.

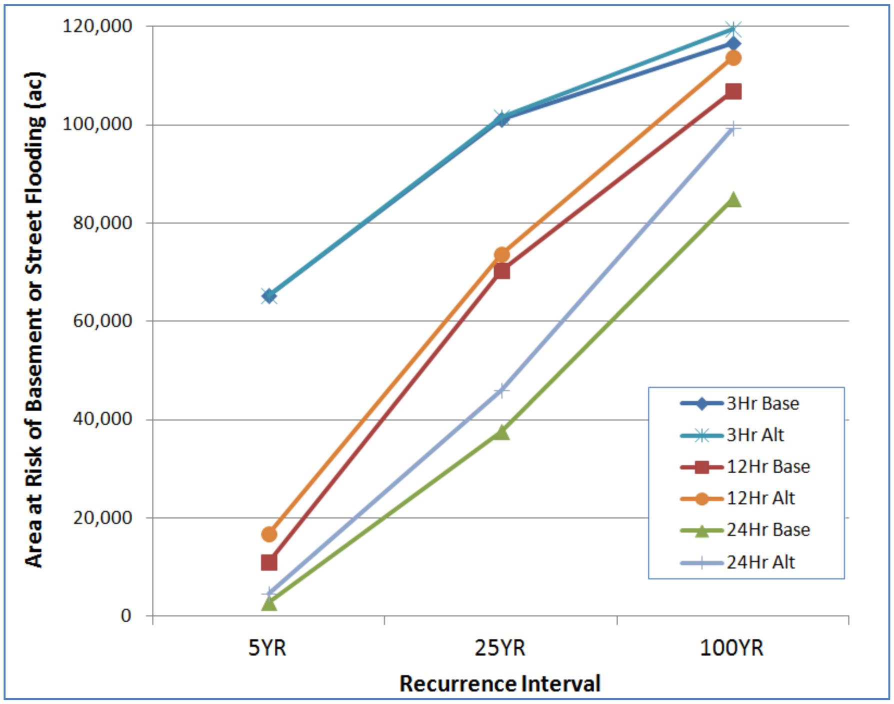
Ideally, the critical duration would be defined based upon comparison of baseline and alternative condition model results. However, because of the project schedule for completion of the overall analysis, alternative conditions model results were not available when the critical duration analysis was performed. The USACE had performed preliminary analysis for the "lock closure" alternative condition (subsequently termed "HS_LAK") for the 2-year, 25-year, and 100-year runs, and the USACE had supplied these model results along with the baseline condition results. The time series hydrographs were reviewed at representative locations including along the CSSC, Wolf Point (junction of the South and North Branches of the Chicago River), and the North Branch of the Chicago River. As expected, the change in peak sewer system level varies by location and annual probability of storm. Based upon review of these results, a means of estimating the elevation offset for each recurrence interval was defined (Table 3-11).

TABLE 3-11
Elevation Offset Applied to Assess Sensitivity to River Level Rise

Return Period	Representation of Water Level Rise
5-yr	Used 50-yr level (rise of 1.1–2.3 ft)
25-yr	Baseline 25-yr level + 1.5 ft
100-yr	Baseline 100-yr level + 4.0 ft

Figure 4-2 summarizes the impact of the increased river level on the flooded area within the entire system. Increased river levels result in a relatively small increase in flooded area for the 3-hour-duration storm event. For the smaller, 5-year recurrence interval storm event (0.2 annual probability), the 12-hour-duration storm event causes slightly greater levels of rise than the 24-hour-duration storm event. However, for the 25- and 100-year recurrence interval events, the 24-hour storm event causes the largest increase in flood extent. Based upon this observation, the 24-hour storm event was selected as the critical duration storm for analysis.

FIGURE 4-2
Critical Duration Area at Risk of Flooding



4.4 Performance Targets

4.4.1 Basement Flooding Threshold

The GLMRIS H&H evaluation of community sewer systems is motivated by the need to understand the extent of additional flood risk associated with river management alternatives. A variety of factors may contribute to basement flooding risk, including the intensity and duration of rainfall events, insufficient trunk sewer capacity, insufficient local sewer capacity, private lateral condition, downstream effects of TARP management, and presence of backflow prevention devices on private property. The basement flood risk threshold is a metric for combined sewer system areas, identifying that a particular part of the system is at risk of flooding based on hydraulic conditions within the system. Basement flood risk is defined when the modeled water level in the sewer exceeds the following thresholds:

- 6 feet below ground for trunk sewers 36 inches in diameter and greater
- 4 feet below ground for trunk sewers less than 36 inches in diameter
- Top of the pipe crown, when it is higher than the threshold defined above

4.4.2 Street Flooding Threshold

The street flooding threshold is defined as the ground elevation. This flooding threshold is applicable for both combined and separate-sewered areas. Limited street flooding is often non-damaging and intentionally included in drainage designs to provide low cost storage.

4.5 Worst-case Evaluations

The H&H sewer system analysis described above represents an idealized approach to quantifying increased sewer system risks associated with increased waterway levels resulting from altered river management scenarios. Uniform rainfall is applied through the system (with areal reduction factors, where appropriate) to estimate both the waterway response and the influence of the waterway response on the sewer system. In reality, spatially heterogeneous rainfall events affect specific areas of the system more than others, and the CAWs and community sewer systems or TARP may not be at dry-weather conditions at the onset of the storm event. Furthermore, timing factors may play a critical role regarding the impact that increased water levels have on the sewer system. For example, significantly different results would be obtained if the storm timing resulted in concurrent peaks of the waterway system and the sewer system. To provide a more comprehensive assessment of the increased risk of flooding associated with river management alternatives, long-term simulation that integrates the three primary hydraulic systems (CAWs, TARP, and community sewers) would be required. This type of analysis is beyond the scope of this study.

5.1 Basement Flooding Risk

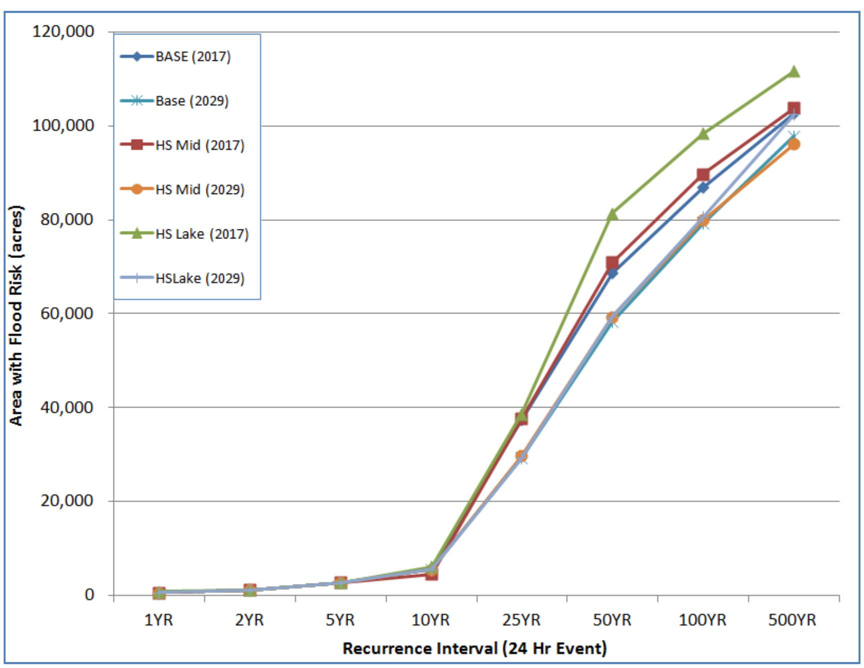
5.1.1 Flood Risk by Scenario

Forty-eight simulations were performed (see Section 4.2). Peak water levels were extracted from the model, and acres at risk of either basement or street flooding (extrapolated from node flooding) were summarized by community for each scenario. Table 5-1 summarizes the aggregate flood risk for the modeled scenarios. Figure 5-1 illustrates the same information.

TABLE 5-1
Simulated Extent of Flood Risk for Modeled River Management Alternatives

	Baseline TARP (2017)			Future TARP (2029)		
Recurrence Interval	BASE [acres]	MID [acres]	Lake [acres]	BASE [acres]	MID [acres]	Lake [acres]
1YR	626	626	818	626	626	626
2YR	1,222	1,199	1,222	1,222	1,222	1,222
5YR	2,759	2,756	2,768	2,759	2,759	2,759
10YR	5,725	4,518	6,174	5,533	5,533	5,533
25YR	37,425	37,693	38,658	29,282	29,797	29,373
50YR	68,757	71,003	81,386	58,318	59,375	59,338
100YR	87,000	89,747	98,401	79,294	79,989	80,612
500YR	102,716	103,874	111,661	97,817	96,124	102,519

FIGURE 5-1
Aggregate Area at Flood Risk for Modeled Communities



Attachment A is a database summarizing peak flood levels and an indicator of basement flooding or street flooding at each drainage node for all modeled scenarios has been provided to the USACE in digital format.

Results summarized by community are included in Appendix B.

5.2 Spatial Variability of Incremental Flood Risk

The degree of baseline system flood risk is highly variable throughout the study area, and depends on a number of factors including the system hydraulic capacity, river level, and TARP availability. Separate sewer systems have a higher flooding threshold (ground level as compared to 4 or 6 feet below ground level for basement flooding), and so generally provide a greater level of service without causing basement flood risk than combined sewer areas.

Figure 5-2 (at the end of this report) shows the smallest magnitude storm event causing flood risk for “without project” 2017 TARP conditions.

Alternative conditions flood risk can be compared to the baseline conditions flood risk to identify increased risk of flooding resulting from alternative conditions. For instance, increased river levels may cause an area to flood for a 5-year storm event, instead of a 50-year storm event, thereby increasing the frequency of flood risk and expected damages resulting from sewer system flooding. Figure 5-3 (at the end of this report) identifies changes in flood risk for the HS_LAK_1 alternative in comparison to WO_XXX_1 (i.e., impact of the HS_LAK separation alternative under 2017 TARP conditions). Figure 5-4 (at the end of this report) presents similar information, instead comparing the 50-year results of HS_LAK_1 to WO_XXX_1. A smaller number of subcatchments have increased risk, because some areas undergo increased basement flooding risk only for smaller or larger storm events.

Note that basement and/or street flooding risk is a metric indicating that a specific threshold has been exceeded for a given modeled scenario. In some instances, an alternative condition may cause an increase in flood level without exceeding this threshold. Alternatively, an area may already exhibit flood risk for a given baseline condition; however, the alternative condition results in higher peak flood levels and a greater duration of flooding. Figure 5-5 (at the end of this report) summarizes the spatial distribution of peak water level rise throughout the system, comparing the 50-year results for the HS_LAK_1 condition to the WO_XXX_1 condition.

SECTION 6

Discussion and Conclusions

The H&H sewer system evaluations provide an integrated assessment of how the CAWs, the TARP system, and community sewer systems interact to affect sewer-system-related basement and street flooding in the study area. Although the results are highly spatially variable and likely vary also by storm event magnitude and duration, nevertheless a few general considerations govern the impact on sewer system flooding:

- Impact of river management alternatives on CAWs water levels
- Availability of TARP system to provide system outlet
- Impact of higher downstream tailwater conditions on upstream sewer system flooding

In general, under 2017 baseline conditions for storms of 10-year magnitude and lower, the modeled sewer systems have capacity to convey wet-weather flows without causing extensive flooding in the study area (this generalization only applies to longer-duration storms such as the 24-hour storm summarized in this document). Basement flooding risk is isolated to localized areas, and risk does not vary considerably, based on either TARP system availability or modeled river scenario. Basement flooding risk in these instances results from local sewer system deficiencies. As the rainfall intensity increases beyond the 25-year intensity, more areas are shown to be at risk of flooding, and the impact of both the river management alternative as well as the TARP condition can be seen. Additional information regarding the variability of TARP benefit in relation to modeled storm intensity is provided in the next paragraph. In general, the HS_LAK alternative results in greater water level increase, which translates to increased additional risk of basement flooding in the system. Although the HS_MID alternative also results in increased basement flooding, the extent of increased flooding is considerably less than with the HS_LAK alternative. For the 2029 TARP condition, the increased risk of basement flooding for the HS_LAK condition is significantly reduced because the increased availability of TARP storage reservoirs reduces the impact of increased CAWs levels.

TARP system performance is a critical component of the overall wet-weather response for the combined sewer portion of the modeled system. When TARP is available, areas served by combined sewers overflow to the TARP tunnel, which provides a downstream outlet, rather than the CAWs. The TARP system, therefore, isolates the sewer system from the impact of increased river levels (assuming that tide gates are present to prevent reverse flow into the sewers from the river). For the Calumet system, the TNET model results show TARP system capacity available up to the 25-year event. Therefore, only for the 50-year event and above do increased river stages translate into increased sewer system levels. In the Mainstream TARP system, however, even under the 2029 condition, in some locations 2-year recurrence interval storm events and greater exhaust the available TARP capacity. This discussion pertains to the idealized, modeled representation of TARP system availability in the TNET model. In reality, TARP is a controlled system, and variability in operation or initial conditions could alter the ability of TARP to isolate combined sewer systems from the increased CAWs levels.

The complex wet-weather system comprising the CAWs, TARP, and community sewer systems is highly interconnected, and the overall system behavior is sensitive to storm event timing, initial conditions in the waterways and TARP reservoirs, and the operation of controlled points in the system. The analysis within this report summarizes the impact of increased waterway levels as provided by the USACE on the sewer system for the 24-hour event. The overall system will respond differently to storm events of varying durations. Shorter-duration storms generally cause more flooding in the sewered areas because of shorter time of concentration. Continuous simulation may allow insight into potential impacts resulting from increased water levels; this is because the different parts of the system (i.e., the CAWs, TARP, and community sewers) may require longer or shorter durations to return to a dry-weather condition, thereby influencing the impact of subsequent or back-to-back storm events. It is important that the potential for alternative storm events (e.g., shorter-duration events) and real-world distribution of rainfall be considered when assessing the potential for adverse impact associated with river management alternatives.

SECTION 7

References

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Figures

Appendix A
A Complete List of the Cross-section Best Representing Levels at Given Outfall

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
CSO_001	NSC 1_1128*
CSO_002	NSC 1_1140
CSO_003	NSC 1_1142*
CSO_004	NSC 1_1152*
CSO_005	NSC 1_1152*
CSO_006	NSC 1_1164
CSO_007	NSC 1_1164
CSO_008	NSC 1_1168
CSO_009	NSC 1_1171*
CSO_010	NSC 1_1171*
CSO_011	NSC 1_1177
CSO_012	NSC 1_1177
CSO_014	NSC 1_1191
CSO_030	NBCR 1_334.81
CSO_034	NBCR 1_333.87
CSO_035	NBCR 1_333.5
CSO_038	NSC 1_1186*
CSO_039	NSC 1_1118*
CSO_040	UNBCR 3_333.067*
CSO_041	UNBCR 3_332.814*
CSO_042	UNBCR 3_332.856
CSO_043	UNBCR 3_332.73
CSO_044	UNBCR 3_332.632*
CSO_045	UNBCR 3_332.584*
CSO_046	UNBCR 3_332.438*
CSO_047	UNBCR 3_332.487*
CSO_048	UNBCR 3_332.326*
CSO_049	UNBCR 3_332.326*
CSO_050	UNBCR 3_332.262*
CSO_051	UNBCR 3_332.23
CSO_052	UNBCR 3_332.23
CSO_057	UNBCR 3_331.96
CSO_058	UNBCR 3_331.685*
CSO_059	UNBCR 3_331.685*
CSO_060	UNBCR 3_331.415
CSO_061	UNBCR 3_331.19
CSO_062	UNBCR 3_331.19
CSO_063	UNBCR 3_330.937

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
CSO_064	UNBCR 3_330.684*
CSO_065	UNBCR 3_330.395
CSO_067	UNBCR 3_330.09*
CSO_068	UNBCR 3_330.01*
CSO_069	UNBCR 3_329.927*
CSO_070	UNBCR 3_329.97
CSO_072	UNBCR 3_329.589*
CSO_073	UNBCR 3_329.28
CSO_074	UNBCR 3_329.28
CSO_075	UNBCR 3_328.888*
CSO_076	UNBCR 3_328.79
CSO_077	UNBCR 3_328.560*
CSO_078	UNBCR 3_328.560*
CSO_079	UNBCR 3_328.423*
CSO_080	UNBCR 3_328.423*
CSO_081	UNBCR 3_328.047
CSO_082	UNBCR 3_327.71
CSO_083	UNBCR 3_327.71
CSO_084	UNBCR 2_327.45
CSO_085	UNBCR 2_327.45
CSO_086	UNBCR-EAST 1_327.13
CSO_087	UNBCR 2_327.21
CSO_088	UNBCR 2_327.19
CSO_089	UNBCR-EAST 1_326.9
CSO_090	UNBCR-EAST 1_326.76
CSO_091	UNBCR-EAST 1_326.72
CSO_092	UNBCR 2_327.05
CSO_093	UNBCR 2_327
CSO_094	UNBCR 2_326.77
CSO_095	UNBCR 2_326.56
CSO_096	UNBCR 1_326.3
CSO_097	UNBCR 1_326.3
CSO_098A	UNBCR 1_326.1
CSO_098B	UNBCR 1_326.1
CSO_099	UNBCR 1_326.1
CSO_100	UNBCR 1_325.91
CSO_101	UNBCR 1_325.71
CSO_103	UNBCR 1_325.54

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
CSO_105	CHICAGO_RIVER 1_1084
CSO_106	CHICAGO_RIVER 1_1090
CSO_107	CHICAGO_RIVER 1_1091
CSO_108	CHICAGO_RIVER 1_1087
CSO_109	CHICAGO_RIVER 1_1094
CSO_110	CHICAGO_RIVER 1_1096
CSO_111	CHICAGO_RIVER 1_1103
CSO_112	CHICAGO_RIVER 1_1106
CSO_113	CHICAGO_RIVER 1_1112
CSO_114	CHICAGO_RIVER 1_1113
CSO_115	CHICAGO_RIVER 1_1118
CSO_116	CHICAGO_RIVER 1_1119
CSO_117E	CHICAGO_RIVER 1_1124
CSO_117W	CHICAGO_RIVER 1_1125
CSO_118	CHICAGO_RIVER 1_1123
CSO_119	CHICAGO_RIVER 1_1130
CSO_120	CHICAGO_RIVER 1_1131
CSO_121	CHICAGO_RIVER 1_1135
CSO_123	CSSC-SBCR 1_325.364*
CSO_125	CSSC-SBCR 1_325.288*
CSO_126	CSSC-SBCR 1_325.2
CSO_127	CSSC-SBCR 1_325.1
CSO_127_North	CSSC-SBCR 1_325.1
CSO_128	CSSC-SBCR 1_325.01
CSO_129	CSSC-SBCR 1_324.95
CSO_130	CSSC-SBCR 1_324.92
CSO_131	CSSC-SBCR 1_324.83
CSO_132	CSSC-SBCR 1_324.63
CSO_133	CSSC-SBCR 1_324.63
CSO_134	CSSC-SBCR 1_324.49
CSO_136	CSSC-SBCR 1_324.31
CSO_137	CSSC-SBCR 1_324.35
CSO_138	CSSC-SBCR 1_324.15
CSO_140	CSSC-SBCR 1_324.01
CSO_141	CSSC-SBCR 1_323.91
CSO_143	CSSC-SBCR 1_323.91
CSO_144	CSSC-SBCR 1_323.76
CSO_145	CSSC-SBCR 1_323.66

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
CSO_146	CSSC-SBCR 1_323.66
CSO_147	CSSC-SBCR 1_323.47
CSO_148	CSSC-SBCR 1_323.47
CSO_149	CSSC-SBCR 1_323.43
CSO_150	CSSC-SBCR 1_323.28
CSO_151	CSSC-SBCR 1_323.18
CSO_152	CSSC-SBCR 1_323.04
CSO_153	CSSC-SBCR 1_323.04
CSO_154	CSSC-SBCR 1_322.89
CSO_155	CSSC-SBCR 1_322.8
CSO_156	CSSC-SBCR 1_322.69
CSO_157	CSSC-SBCR 1_322.61
CSO_158	CSSC-SBCR 1_322.61
CSO_159	CSSC-SBCR 1_322.35
CSO_160	CSSC-SBCR 1_322.27
CSO_161	CSSC-SBCR 1_322.1
CSO_162	CSSC-SBCR 1_322
CSO_163	CSSC-SBCR 1_322
CSO_164	CSSC-SBCR 1_321.79
CSO_165	CSSC-SBCR 1_321.75
CSO_166	CSSC-SBCR 1_321.64
CSO_167	CSSC-SBCR 2_321.5
CSO_168	CSSC-SBCR 2_321.37
CSO_170	CSSC-SBCR 2_320.94
CSO_172	CSSC-SBCR 2_320.51
CSO_173	CSSC-SBCR 2_320.38
CSO_174	CSSC-SBCR 2_320.2
CSO_176	CSSC-SBCR 2_319.83
CSO_179	CSSC-SBCR 2_319.33
CSO_180	CSSC-SBCR 2_319.29
CSO_181	CSSC-SBCR 2_318.76
CSO_182	CSSC-SBCR 2_318.64
CSO_183	CSSC-SBCR 2_318.23
CSO_184	CSSC-SBCR 2_318.21
CSO_185	CSSC-SBCR 2_317.51
CSO_186	CSSC-SBCR 2_317.13
CSO_187	CSSC-SBCR 2_316.61
CSO_188	CSSC-SBCR 2_314.67

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
CSO_189	CSSC-SBCR 2_314.58
CSO_190	BUBBLY_CREEK 1_321.83
CSO_191	BUBBLY_CREEK 1_322.04
CSO_192	BUBBLY_CREEK 1_322.04
CSO_193	BUBBLY_CREEK 1_322.12
CSO_194	BUBBLY_CREEK 1_322.72
CSO_195	BUBBLY_CREEK 1_322.72
CSO_196	BUBBLY_CREEK 1_322.98
CSO_197	BUBBLY_CREEK 1_322.98
CSO_198	BUBBLY_CREEK 1_323.09
CSO_206	WEST GRAND CAL REACH # 2_0.171
CSO_209	CALUMET-LCRN LOWER_322.27
CSO_210	CALUMET-LCRN LOWER_322.27
CSO_211	CALUMET-LCRN LOWER_321.4
CSO_214	CALUMET-LCRN LOWER_320.33
CSO_215	CALUMET-LCRN LOWER_320.33
CSO_216	CALUMET-LCRN LOWER_319.6
CSO_218	CAL_SAG 1_319.13
CSO_230	UNBCR-EAST 1_326.6
CSO_231	UNBCR 3_331.415
CSO_233	NSC 1_1186*
CSO_235	NBCR 1_333.958*
CSO_237	UNBCR 2_326.56
CSO_238	UNBCR 3_330.768*
CSO_239	CALUMET-LCRN LOWER_322.6
CSO_241	CALUMET-LCRN LOWER_320.58
CSO_MWRD107	UNBCR 3_332.898*
CSO_MWRD107_North	UNBCR 3_332.898*
CSO_MWRD142	BUBBLY_CREEK 1_323.09
CSO_MWRD151	CALUMET-LCRN 1_1030
CSO_MWRD152	CALUMET-LCRN 1_1130
CSO_MWRD153	CALUMET-LCRN LOWER_321.22
CSO_MWRD154	CAL_SAG 1_319.32
CSO_178	CSSC-SBCR 2_319.57
CSO_104	CHICAGO_RIVER 1_1062
PAHI_000817	CAL_SAG 1_308.76
PAHI_000269	CAL_SAG 1_308.87
PAHI_000416	CAL_SAG 1_308.92

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
PAHI_000788	CAL_SAG 1_309.03
PAHI_000839	CAL_SAG 1_309.64
PAHI_000838	CAL_SAG 1_309.76
PAHI_000511	CAL_SAG 1_309.92
PAHI_000829	CAL_SAG 1_310.08
PAHI_000872	CAL_SAG 1_310.26
PAHI_000515	CAL_SAG 1_310.31
PAHI_000433	CAL_SAG 1_310.57
CDS02_Central_Park_Ave_ext_(N)	CAL_SAG 1_316.46
CDS04_Sacramento_Ave_ext_(S)	CAL_SAG 1_317.23
CDS05_Francisco_Ave_(N)	CAL_SAG 1_317.34
CDS06_California_Ave_&_Edward_	CAL_SAG 1_317.47
BLUE_0112	CAL_SAG 1_317.94
CDS07_Irving_Ave_(West_of_Fult	CAL_SAG 1_318.12
CDS08_Division_Ave_(S)	CAL_SAG 1_318.46
CDS09_Division_Ave_(N)	CAL_SAG 1_318.5
SOHO_0235	CALUMET UNION REACH 1_1978
SOHO_0633	CALUMET UNION REACH 1_2833
SOHO_0330	CALUMET UNION REACH 1_2833
SOHO_0332	CALUMET UNION REACH 1_2934
SOHO_0273	CALUMET UNION REACH 1_5754
SOHO_0226	CALUMET UNION REACH 1_258
HARV_0360	CALUMET UNION REACH 1_7638
HARV_0308	CALUMET UNION REACH 1_8968
HARV_0369	CALUMET UNION REACH 1_8968
HARV_0362	CALUMET UNION REACH 1_9042
HARV_0367	CALUMET UNION REACH 1_9677
SOHO_0230	CALUMET UNION REACH 1_258
HARV_0365	CALUMET UNION REACH 1_9677
HARV_0015	CALUMET UNION REACH 1_9734
HARV_0016	CALUMET UNION REACH 2_12176
CDS57_161st_St_&_Damen_Ave_(Ma	CALUMET UNION REACH 3_16353
4B0183	4B0183_Constant
CDS15-1_Penn_Central_RR_&_Dear	CALUMET-LCRN LOWER_321.96
CDS15-3_Ext_State_St_(ACME_Ste	CALUMET-LCRN LOWER_322.03
CDS15_Wabash_(IL_Central_RR)_(	CALUMET-LCRN LOWER_322.06
CDS15-4_Indiana_Ave_(East_of_W	CALUMET-LCRN LOWER_322.13
CDS17_Park_Ave_(Forest_Av_Ext)	CALUMET-LCRN LOWER_322.64

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
CDS18_Dorchester_Ave_ext_(S)	CALUMET-LCRN LOWER_324.26
CACI_0258	CALUMET-LCRN LOWER_325.04
HARV_0358	CANADIAN CENTRAL REACH 1_3922.6*
FRVW_0006	CSSC-SBCR 2_314.4
SOHO_0506	LC UNNAMED TRIB REACH 1_2546
SOHO_0510	LC UNNAMED TRIB REACH 1_2602
SOHO_0514	LC UNNAMED TRIB REACH 1_2994.93*
SOHO_0451	LC UNNAMED TRIB REACH 1_3324
SOHO_0444	LC UNNAMED TRIB REACH 1_3527
SOHO_0465	LC UNNAMED TRIB REACH 1_3855
SOHO_0385	LC UNNAMED TRIB REACH 1_3865
BLUE_0118	LITTLE CALUMET W REACH 1_6519
CDS39_Ashland_Ave_(S)	LITTLE CALUMET W REACH 2_10608
CDS41_144th_St_(W)	LITTLE CALUMET W REACH 2_16057
CDS41_Center_Ave_(E)	LITTLE CALUMET W REACH 2_16755.4*
CDS42_Union_St_(W)	LITTLE CALUMET W REACH 2_18482.6*
CDS42_Union_Ave_P.S._(N)	LITTLE CALUMET W REACH 2_18704.2*
CDS43_Clinton_St_(W)	LITTLE CALUMET W REACH 2_20015
CDS43_Illinois_Central_Railroa	LITTLE CALUMET W REACH 2_20477
DLTN_1141	LITTLE CALUMET W REACH 2_21410.6*
DLTN_1144	LITTLE CALUMET W REACH 2_22140.5*
DLTN_1145	LITTLE CALUMET W REACH 2_22429.7*
DLTN_1147	LITTLE CALUMET W REACH 2_22837
HARV_0010	LITTLE CALUMET W REACH 2_22905
CDS45_149th_St_(E)	LITTLE CALUMET W REACH 2_24300
CDS45_9th_Ave_ext_&_151st_St_	LITTLE CALUMET W REACH 2_25221
SOHO_0483	LITTLE CALUMET W REACH 2_26249.*
SOHO_0229	LITTLE CALUMET W REACH 2_26602.*
SOHO_0323	LITTLE CALUMET W REACH 2_27493
SOHO_0056	LITTLE CALUMET W REACH 2_27589
SOHO_0523	LITTLE CALUMET W REACH 2_28007.3*
SOHO_0002	LITTLE CALUMET W REACH 2_28590.*
CDS48_State_St._(155th_&_Woodl	LITTLE CALUMET W REACH 2_29059.6*
SOHO_0141	LITTLE CALUMET W REACH 2_29849.*
SOHO_0143	LITTLE CALUMET W REACH 2_30505
CDSC1_South_Park_Ave_(N)	LITTLE CALUMET W REACH 3_34139
CDSC1_South_Park_Ave_(S)	LITTLE CALUMET W REACH 3_34179
SOHO_0223	LITTLE CALUMET W REACH 3_35877

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
SOHO_0247	LITTLE CALUMET W REACH 3_36584
SOHO_0423	LITTLE CALUMET W REACH 3_36874
SOHO_0334	LITTLE CALUMET W REACH 3_37231.5*
SOHO_0290	LITTLE CALUMET W REACH 3_37504
SOHO_0257	LITTLE CALUMET W REACH 3_38065
CDS51_Ellis_Ave_(N)	LITTLE CALUMET W REACH 3_38203.*
SOHO_0233	LITTLE CALUMET W REACH 3_38479.*
SOHO_0178	LITTLE CALUMET W REACH 3_39239.5*
SOHO_0123	LITTLE CALUMET W REACH 3_39504.*
SOHO_0004	LITTLE CALUMET W REACH 3_39653.*
SOHO_0111	LITTLE CALUMET W REACH 3_40671
SOHO_0357	LITTLE CALUMET W REACH 3_41263.3*
CACI_0191	LITTLE CALUMET W REACH 3_43091.5*
SOHO_0554	LITTLE CALUMET W REACH 5_48540.3*
SOHO_0501	LITTLE CALUMET W REACH 5_48960.8*
SOHO_0468	LITTLE CALUMET W REACH 5_51303.4*
CACI_0209	LITTLE CALUMET W REACH 5_52046
CACI_0228	LITTLE CALUMET W REACH 5_55999.9*
CDS53_River_Dr_(N)	LITTLE CALUMET W REACH 5_57951.4*
CDS53_Woodview_Ave_(N)	LITTLE CALUMET W REACH 5_58940
CDS55_Green_Bay_Ave_(N)!	LITTLE CALUMET W REACH 5_60692
CDS55_Burnham_Ave_(N)!	LITTLE CALUMET W REACH 5_63229
CDS55_Burnham_Ave_(170th_St)_!	LITTLE CALUMET W REACH 5_63309
CDS55_Lincoln_Ave_(N)!	LITTLE CALUMET W REACH 5_65953.0*
PAHI_000525	LUCAS DITCH LUCAS DITCH_1028.96*
PAHI_000316	LUCAS DITCH LUCAS DITCH_2841.899
PAHI_000431	LUCAS DITCH LUCAS DITCH_3397.251
PAHI_000496	LUCAS DITCH LUCAS DITCH_343.5076
PAHI_000537	LUCAS DITCH LUCAS DITCH_4114.692
PAHI_000775	LUCAS DITCH LUCAS DITCH_4439.478
PAHI_000755	LUCAS DITCH LUCAS DITCH_4578.062
PAHI_000588	LUCAS DITCH LUCAS DITCH_4655.805
PAHI_000586	LUCAS DITCH LUCAS DITCH_4719
PAHI_000580	LUCAS DITCH LUCAS DITCH_5230.943
PAHI_000566	LUCAS DITCH LUCAS DITCH_5836.943
PAHI_000568	LUCAS DITCH LUCAS DITCH_5934.508
PAHI_000945	LUCAS DITCH LUCAS DITCH_6047.235
PAHI_000502	LUCAS DITCH LUCAS DITCH_629.7694

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
PAHI_000640	LUCAS DITCH LUCAS DITCH_6749.639
PAHI_000259	LUCAS DITCH LUCAS DITCH_733.9876
PAHI_000885	LUCAS DITCH LUCAS DITCH_7650.485
PAHI_000881	LUCAS DITCH LUCAS DITCH_7733.302
PAHI_000424	LUCAS DITCH LUCAS DITCH_844.716
PAHI_000777	LUCAS DITCH LUCAS DITCH_980.496*
PAHI_000747	LUCAS DIVERSION LUCAS DIVERSION_1970.135
PAHI_000749	LUCAS DIVERSION LUCAS DIVERSION_2247.93*
PAHI_000349	LUCAS DIVERSION LUCAS DIVERSION_2525.73*
PAHI_000601	LUCAS DIVERSION LUCAS DIVERSION_2890.912
PAHI_000445	LUCAS DIVERSION LUCAS DIVERSION_3591.887
PAHI_000446	LUCAS DIVERSION LUCAS DIVERSION_3776.402
PAHI_000937	LUCAS DIVERSION LUCAS DIVERSION_4406.089
PAHI_000935	LUCAS DIVERSION LUCAS DIVERSION_5578.321
BLUE_0116	MIDLOTHIAN CR 1_1786.079
BLUE_0101	MIDLOTHIAN CR 1_5742.22*
HARV_0035	LITTLE CALUMET W REACH 2_10899
SOHO_0519	THORN CREEK REACH 1_10349
SOHO_0521	THORN CREEK REACH 1_12485.2*
SOHO_0416	THORN CREEK REACH 1_14019.1*
SOHO_0349	THORN CREEK REACH 1_14937
SOHO_0347	THORN CREEK REACH 1_15210.1*
SOHO_0435	THORN CREEK REACH 1_2263.85*
SOHO_0530	THORN CREEK REACH 1_2351.57*
SOHO_0438	THORN CREEK REACH 1_4130.33*
SOHO_0503	THORN CREEK REACH 1_5678
SOHO_0485	THORN CREEK REACH 1_6394.6*
SOHO_0412	THORN CREEK REACH 1_6936.*
SOHO_0486	THORN CREEK REACH 1_7592.36*
SOHO_0488	THORN CREEK REACH 1_7884.72*
SOHO_0225	THORN CREEK REACH 1_9671.27*
SOHO_0003	THORN CREEK REACH 1_9864.90*
PAHI_000465	W STONY CR DN W STCR 1_.128*
PAHI_000818	W STONY CR DN W STCR 1_.198*
PAHI_000766	W STONY CR DN W STCR 2_.741571*
PAHI_000411	W STONY CR DN W STCR 2_.956142*
PAHI_000336	W STONY CR DN W STCR 2_.995714*
PAHI_000746	W STONY CR DN W STCR 2_0.611

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
PAHI_000830	W STONY CR DN W STCR 2_0.63
PAHI_000287	W STONY CR DN W STCR 2_1.03528*
PAHI_000753	W STONY CR DN W STCR 2_1.11442*
PAHI_000432	W STONY CR DN W STCR 2_1.154
PAHI_000453	W STONY CR DN W STCR 2_1.24914*
PAHI_000450	W STONY CR DN W STCR 2_1.28085*
PAHI_000382	W STONY CR DN W STCR 2_1.34428*
PAHI_000451	W STONY CR DN W STCR 2_1.376
PAHI_000449	W STONY CR DN W STCR 2_1.404
PAHI_000739	W STONY CR DN W STCR 2_1.405
PAHI_000750	W STONY CR DN W STCR 2_1.45433*
PAHI_000448	W STONY CR DN W STCR 2_1.507
PAHI_000939	W STONY CR DN W STCR 2_1.6054*
PAHI_000947	W STONY CR DN W STCR 3_1.6882*
PAHI_000840	W STONY CR DN W STCR 3_1.94930*
PAHI_000852	W STONY CR DN W STCR 3_2.507
PAHI_000855	W STONY CR DN W STCR 3_2.526
CDS21_Escanaba_Ave_near_138th_	WEST GRAND CAL REACH # 2_.458729*
BRNM_0306	WEST GRAND CAL REACH # 2_0.507
BRNM_222	WEST GRAND CAL REACH # 2_0.811
BRNM_190	WEST GRAND CAL REACH # 2_1.12754*
CDS24_Burnham_Ave_(S)	WEST GRAND CAL REACH # 2_1.80420*
CACI_0254	WEST GRAND CAL REACH # 2_2.114
PAHI_00952	LUCAS DITCH LUCAS DITCH_10698.01
PAHI_000835	LUCAS DITCH LUCAS DITCH_629.7694
PAHI_000504	LUCAS DITCH LUCAS DITCH_733.9876
PAHI_000821	LUCAS DITCH LUCAS DITCH_733.9876
PAHI_000822	LUCAS DITCH LUCAS DITCH_733.9876
PAHI_000779	LUCAS DITCH LUCAS DITCH_980.496*
PAHI_000774	LUCAS DITCH LUCAS DITCH_1028.96*
PAHI_000761	LUCAS DITCH LUCAS DITCH_2841.899
PAHI_000780	LUCAS DITCH LUCAS DITCH_3397.251
PAHI_000769	LUCAS DITCH LUCAS DITCH_3397.251
PAHI_000770	LUCAS DITCH LUCAS DITCH_3397.251
PAHI_000554	LUCAS DITCH LUCAS DITCH_4114.692
PAHI_000591	LUCAS DITCH LUCAS DITCH_4655.805
PAHI_000594	LUCAS DITCH LUCAS DITCH_5230.943
PAHI_000785	LUCAS DITCH LUCAS DITCH_5230.943

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
PAHI_000786	LUCAS DITCH LUCAS DITCH_5836.943
PAHI_000570	LUCAS DITCH LUCAS DITCH_5836.943
PAHI_000886	LUCAS DITCH LUCAS DITCH_5934.508
PAHI_000756	LUCAS DITCH LUCAS DITCH_6749.639
PAHI_000943	LUCAS DITCH LUCAS DITCH_6749.639
PAHI_9901	LUCAS DITCH LUCAS DITCH_6749.639
PAHI_000883	LUCAS DITCH LUCAS DITCH_7733.302
PAHI_000820	W STONY CR DN W STCR 1_.198*
PAHI_000651	W STONY CR DN W STCR 2_0.611
PAHI_000338	W STONY CR DN W STCR 2_1.03528*
PAHI_000758	W STONY CR DN W STCR 2_1.11442*
PAHI_000444	W STONY CR DN W STCR 2_1.34428*
PAHI_000949	W STONY CR DN W STCR 2_1.507
PAHI_000751	W STONY CR DN W STCR 2_1.45433*
PAHI_000748	LUCAS DIVERSION LUCAS DIVERSION_2525.73*
PAHI_000689	LUCAS DIVERSION LUCAS DIVERSION_3591.887
PAHI_000941	W STONY CR DN W STCR 3_1.94930*
PAHI_000873	CAL_SAG 1_310.26
PAHI_000832	CAL_SAG 1_310.26
HARV_0012	LITTLE CALUMET W REACH 2_22905
DLTN_1148	LITTLE CALUMET W REACH 2_22837
CDS45_152nd_St_ext_W_Structur1	LITTLE CALUMET W REACH 2_24300
CDS45_152nd_St_ext_W_Structur2	LITTLE CALUMET W REACH 2_24300
HARV_0372	CALUMET UNION REACH 1_8968
HARV_0382	CALUMET UNION REACH 1_5754
SOHO_0607	CALUMET UNION REACH 1_5754
SOHO_0632	CALUMET UNION REACH 1_1978
SOHO_0232	CALUMET UNION REACH 1_258
SOHO_0150	LITTLE CALUMET W REACH 3_34179
SOHO_0629	LITTLE CALUMET W REACH 3_34179
SOHO_0245	LITTLE CALUMET W REACH 3_35877
SOHO_0612	LITTLE CALUMET W REACH 3_36874
SOHO_0389	LC UNNAMED TRIB REACH 1_3865
SOHO_0392	LC UNNAMED TRIB REACH 1_3865
SOHO_0393	LC UNNAMED TRIB REACH 1_3865
SOHO_0400	LC UNNAMED TRIB REACH 1_3865
SOHO_0403	LC UNNAMED TRIB REACH 1_3865
SOHO_0404	LC UNNAMED TRIB REACH 1_3865

TABLE A-1
Waterway Cross Sections Assigned to Modeled Outfalls

H&H Modeled Outfall	Waterway Modeled Cross Section
SOHO_0441	THORN CREEK REACH 1_2263.85*
CDS23_E_of_142nd_St._ext_and_M	WEST GRAND CAL REACH # 2_1.12754*
CDS22_138th_Pl._ext_(N)	WEST GRAND CAL REACH # 2_0.507
OUT_EVST_15741	NSC 1_1111*
EVST_18085	NSC 1_1100
OUT_EVST_Main_St	NSC 1_1094*
EVST_15693	NSC 1_1088*
OUT_EVST_17314	NSC 1_1076*
OUT_EVST_McDaniel	NSC 1_1064*
OUT_EVST_16164	NSC 1_1064*
OUT_EVST_16097	NSC 1_1053*
OUT_EVST_17588	NSC 1_1053*
EVST_VI_OUT	NSC 1_1046*
OUT_EVST_16826	NSC 1_1043*
OUT_EVST_18153	NSC 1_1040*
OUT_EVST_15708	NSC 1_1037
OUT_EVST_16981	NSC 1_1036*
OUT_EVST_16877	NSC 1_1036*
OUT_EVST_17243	NSC 1_1025*
SOHO_0414	LC UNNAMED TRIB REACH 1_3855
PAHI_00099.O_Outfall	W STONY CR DN W STCR 2_1.24914*

Appendix B
Aggregate Flood Risk by Community

	Storm	TARP_Existing			TARP Future		
		BASE	MID	Lake	BASE	MID	Lake
Blue Island [416 acres]	1YR	63	63	63	63	63	63
	2YR	63	63	63	63	63	63
	5YR	63	63	63	63	63	63
	10YR	112	112	112	112	112	112
	25YR	167	167	167	167	167	167
	50YR	167	167	167	167	167	167
	100YR	171	167	230	167	167	171
	500YR	232	192	295	232	192	295
Burnham [307 acres]	1YR	-	-	-	-	-	-
	2YR	-	-	-	-	-	-
	5YR	-	-	-	-	-	-
	10YR	56	56	56	56	56	56
	25YR	129	129	129	129	129	129
	50YR	231	212	212	212	212	212
	100YR	231	212	212	223	212	212
	500YR	219	212	212	231	212	212
Calumet City [3,169 acres]	1YR	-	-	-	-	-	-
	2YR	-	-	-	-	-	-
	5YR	529	529	529	529	529	529
	10YR	1,026	1,026	1,026	1,026	1,026	1,026
	25YR	2,188	2,188	2,188	2,188	2,188	2,188
	50YR	2,870	2,809	2,870	2,870	2,870	2,870
	100YR	2,870	2,837	2,870	2,870	2,870	2,870
	500YR	2,900	2,856	2,880	2,900	2,900	2,880
Chicago [130,274 acres]	1YR	213	213	460	213	213	213
	2YR	643	643	643	643	643	643
	5YR	1,056	1,056	1,065	1,056	1,056	1,056
	10YR	1,916	1,797	2,403	1,724	1,724	1,724
	25YR	33,267	33,619	34,497	24,539	25,072	24,631
	50YR	65,153	67,770	78,421	54,236	55,329	55,055
	100YR	82,960	86,345	95,176	75,128	75,869	76,683
	500YR	99,138	101,293	108,609	93,794	91,962	98,651

	Storm	TARP_Existing BASE	TARP_Existing MID	TARP_Existing Lake	TARP Future BASE	TARP Future MID	TARP Future Lake
Dolton [3,283 acres]	1YR	439	439	439	439	439	439
	2YR	1,017	1,017	1,017	1,017	1,017	1,017
	5YR	1,986	1,986	1,986	1,986	1,986	1,986
	10YR	2,763	2,763	2,763	2,763	2,763	2,763
	25YR	2,854	2,819	2,854	2,854	2,854	2,854
	50YR	3,071	2,953	3,071	3,071	3,071	3,071
	100YR	3,071	3,022	3,071	3,071	3,071	3,071
	500YR	3,176	3,115	3,176	3,176	3,176	3,176
Evanston [4,052 acres]	1YR	-	-	-	-	-	-
	2YR	-	-	-	-	-	-
	5YR	-	-	-	-	-	-
	10YR	-	-	18	-	-	-
	25YR	-	-	18	18	-	18
	50YR	360	360	427	360	360	607
	100YR	509	564	856	478	478	694
	500YR	839	870	1,154	799	799	1,041
Forest View [70 acres]	1YR	-	-	-	-	-	-
	2YR	-	-	-	-	-	-
	5YR	-	-	-	-	-	-
	10YR	-	-	-	-	-	-
	25YR	-	-	-	-	-	-
	50YR	37	30	57	30	30	30
	100YR	57	48	57	48	48	48
	500YR	57	57	70	57	57	57
Harvey [3,927 acres]	1YR	-	-	-	-	-	-
	2YR	43	43	43	43	43	43
	5YR	442	442	442	442	442	442
	10YR	469	469	469	469	469	469
	25YR	2,395	2,395	2,395	2,395	2,395	2,395
	50YR	2,730	2,669	2,688	2,688	2,688	2,688
	100YR	3,192	2,974	2,997	2,997	2,997	2,997
	500YR	3,604	3,289	3,478	3,456	3,456	3,456

	Storm	TARP_Existing BASE	TARP_Existing MID	TARP_Existing Lake	TARP Future BASE	TARP Future MID	TARP Future Lake
Palos Hills [3,627 acres]	1YR	31	31	31	31	31	31
	2YR	31	31	31	31	31	31
	5YR	55	52	55	55	55	55
	10YR	1,158	69	1,158	1,158	1,158	1,158
	25YR	1,225	1,184	1,225	1,225	1,225	1,225
	50YR	1,285	1,266	1,285	1,285	1,285	1,285
	100YR	2,173	2,119	2,173	2,173	2,173	2,173
	500YR	2,389	2,178	2,547	2,389	2,388	2,394
South Holland [3,435 acres]	1YR	-	-	-	-	-	-
	2YR	45	-	45	45	45	45
	5YR	45	45	45	45	45	45
	10YR	130	130	130	130	130	130
	25YR	449	449	449	449	449	449
	50YR	1,106	1,079	1,106	1,106	1,106	1,093
	100YR	1,622	1,539	1,587	1,622	1,622	1,587
	500YR	2,207	1,792	2,093	2,207	2,207	2,093

Attachment A
Database of Peak Flood Levels