Stormwater Management in Chicago waterways

:Basement Flooding and its prevention

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CE 394K GIS in Water Resources - David R. Maidment.

Dec 4th 2015

Motivation and Objective

Recently, Chicago area is suffered from urban flooding because of localized heavy rainfall with high intensity. Their local sewer system is quite old which cannot hold that heavy amount of rainfall causing flooding. The urbanization is one of the factors of flooding in Chicago. Land use has been changed a lot from green areas to paved road and urban area which is impermeable; therefore, the impervious area is acting like a barrier for rainfall not to infiltrate into the ground. Nowak et al. tried to track the change of tree and impermeable area in 20 cities in US from 2005 to 2009 (2012). The twenty cities average has negative 1.5 for change in tree area and positive 1.3 for impervious area. This average is clearly presented at Chicago Area with negative 0.5 for tree area and zero change for impervious area. Even impervious area change has not been tracked, it is clear that tree area is smaller than 4 years before. It causes surface runoff and flooding that the huge volume of runoff fills stream and rivers exceeding their capacity.

In terms of heavy rainfalls, the precipitation in this June hit the record during last 120 years. State Climatologist Office for Illinois has been started record the rainfall record from 1895 and the wettest record since 1895 was 1902 as 8.27 inches. The record sets again in this June 2015 as 8.97 inches.

Figure 1: Wettest June on record in Illinois

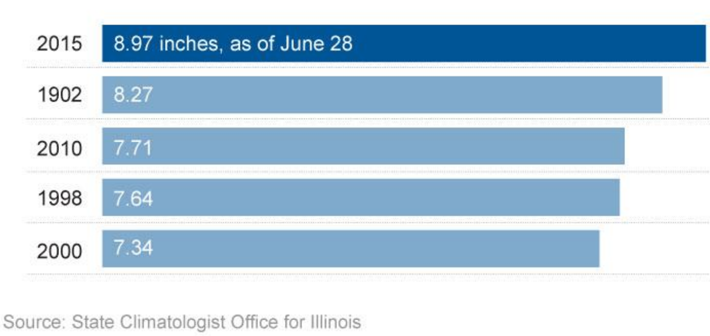
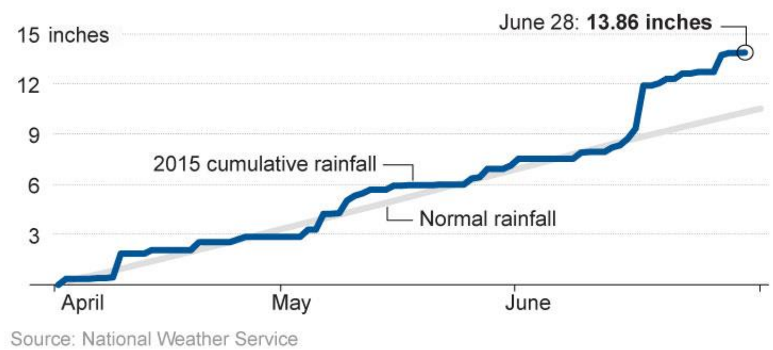


Figure 2: Chicago Rainfall: 2015 vs. normal (cumulative by day)



It is able to track cumulative rainfall based on normal rainfall pattern presented by National Weather Service. As shown in Figure 2, cumulative rainfall 2015 has excessive drawing rather than normal rainfall. Based on normal distribution, cumulative one should have around 10 inches but it is a way more than 13 inches.

The Tunnel and Reservoir Plan (TARP) is a deep underground tunnels and huge reservoirs to store combined sewer overflows (CSOs) of Chicago area to prevent frequent flooding and improve water quality. This project has been started from 1970's and it is currently on the final stage. In this term project, it would be explore how TARP influences Chicago waterways in terms of storm water management in Chicago area using a geographic information system (GIS). Since most of the drainage system is connected underground because of TARP, it was not able to enough data on NHDPlus for mapping on ArcGIS. However, I still keep using ArcGIS since It is a great tool for visualizing the TARP facilities, output and its impact.

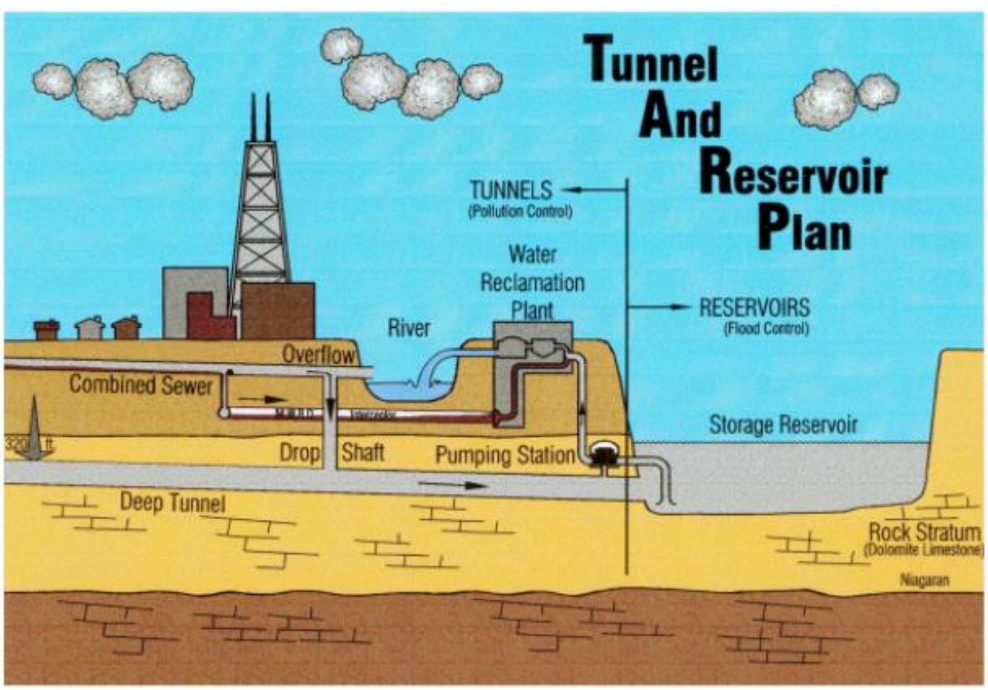


Figure 3: Tunnel and Reservoir Plan

Methodology

All data and pre-presented map are available from U.S. Geological Survey (USGS) and ESRI data services. As illustrated above, most of the drainage and pipe systems are connected underground in Chicago area, there are only four USGS stream gage stations are available to figure out how many overflow is controlled. Soil type data came from U.S. Soil Conservation Service (NRCS) to present which area is vulnerable to flooding since flooding mostly happens because of surface overflow.

Study Area

The study area is a subject of Tunnel and Reservoir Plan which is Chicago area. It covers few suburban area sharing a lake or streams with Chicago. There are three reservoirs including TARP: O'Hare, McCook and Thorton reservoirs. Figure 4 is a layered map overlaying USGS stations, basins and counties over the pre-made map presented a location of each reservoir, tunnels and their connections.

From the top green dot, each dot presents O'hare, McCook and Thornton Reservoirs and yellow dots are USGS stream gage station influencing each reservoir From the top yellow dot: USGS 05536105 NB CHICAGO RIVER AT ALBANY AVENUE AT CHICAGO, IL (O'hare), USGS 05536118 N.B. Chicago River at Grand Ave at Chicago, IL (McCook), USGS 04092500 Wolf Lake at Chicago, IL and USGS 05536358 CALUMET R BLW OBRIEN LOCK AND DAM AT CHICAGO, IL (Thornton). Red lines depicts tunnel in TARP system. A layered map over the Figure 4 is shown in Figure 5. Floodwater discharges to the Lake Michigan to the left side of both maps.

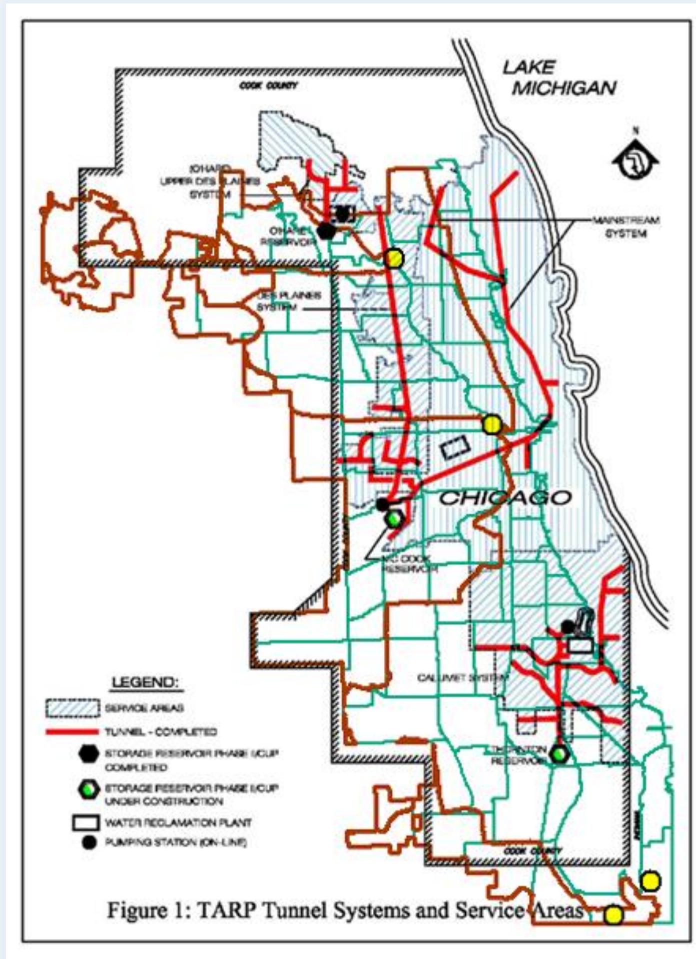


Figure 4: TARP Tunnel Systems and Service Areas prepared by Metropolitan Water Reclamation District of Greater Chicago (MWRD)

Figure 6 and Table 1 highlights soil type distribution in Chicago area. As shown in a map and a table, clay loam is the primary soil type in Chicago. Clay loam has two biggest drawbacks to work with, wetness and poor drainage, both make not to water infiltrate in to the ground and make surface flow which is flooding. Main soil type distribution may cause frequent flooding in Chicago.

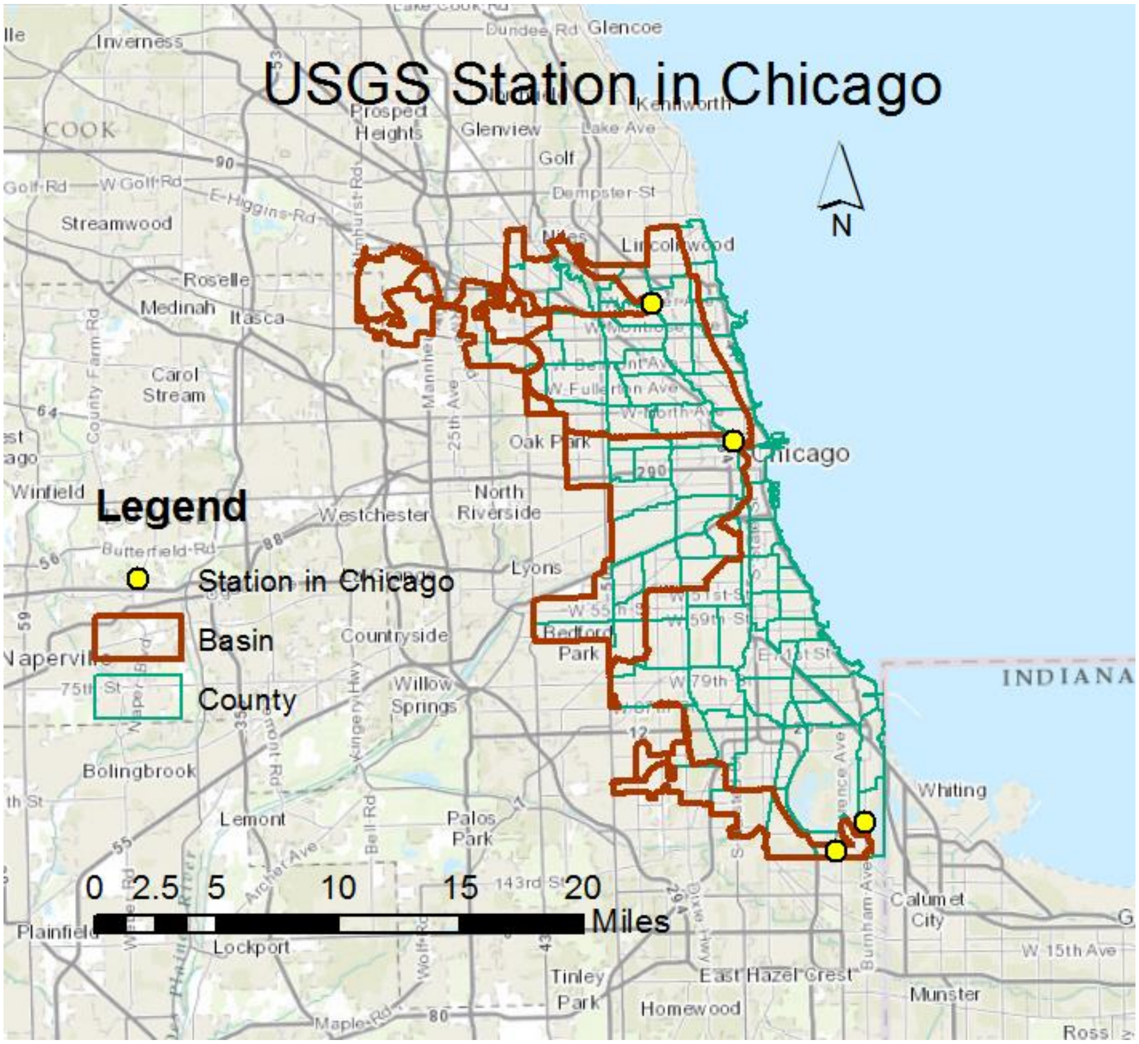


Figure 5

Table 1: Soil type in Chicago

	Soil	Area(m^2)	%
10	Sandy Clay	581822780	3.339
12	Clay	1087259600	6.24
13	Organic Materials	2034917892	11.679
7	Sandy Clay loam	5218452024	29.95
8	Silty clay loam	705480450	4.049
9	Clay loam	4309253252	24.731
5	Silt	806876796	4.631

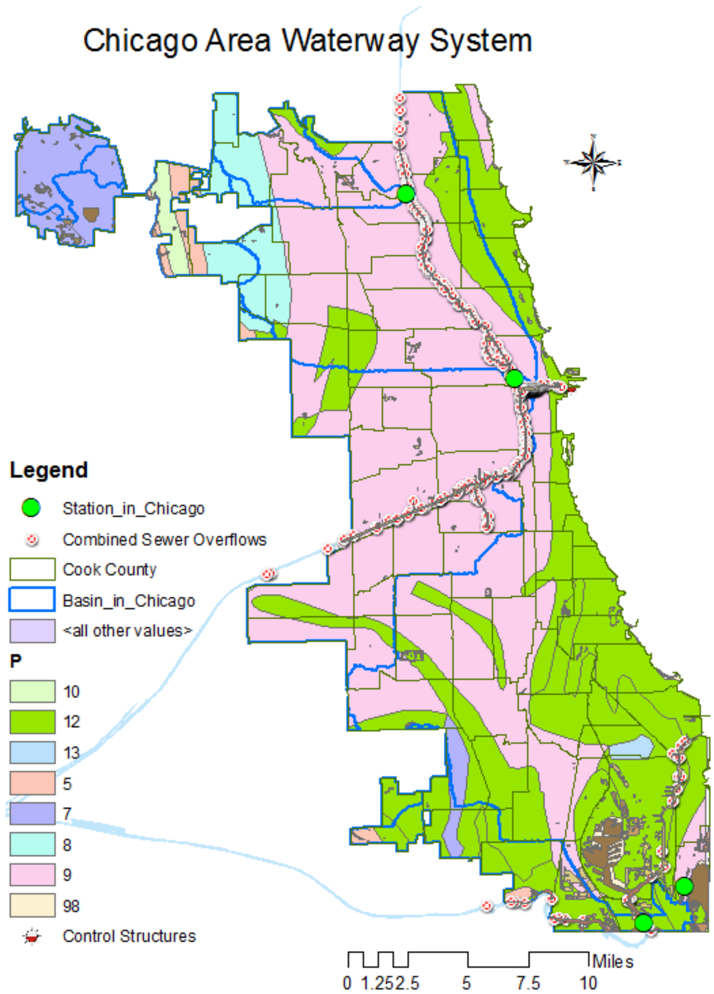


Figure 6

Analysis and Result

1. *Annual Discharge and Gage Height at USGS Gages*

There are 4 gages in the subjected area but only 3 gages have relevant discharge and gage height data. From the top among 4 gages, the third one, USGS 04092500 Wolf Lake at Chicago, IL does not have any available data. The others have data on gages but they are not enough to analyze an impact of TARP project.

- USGS05536105 NB CHICAGO RIVER AT ALBANY AVENUE

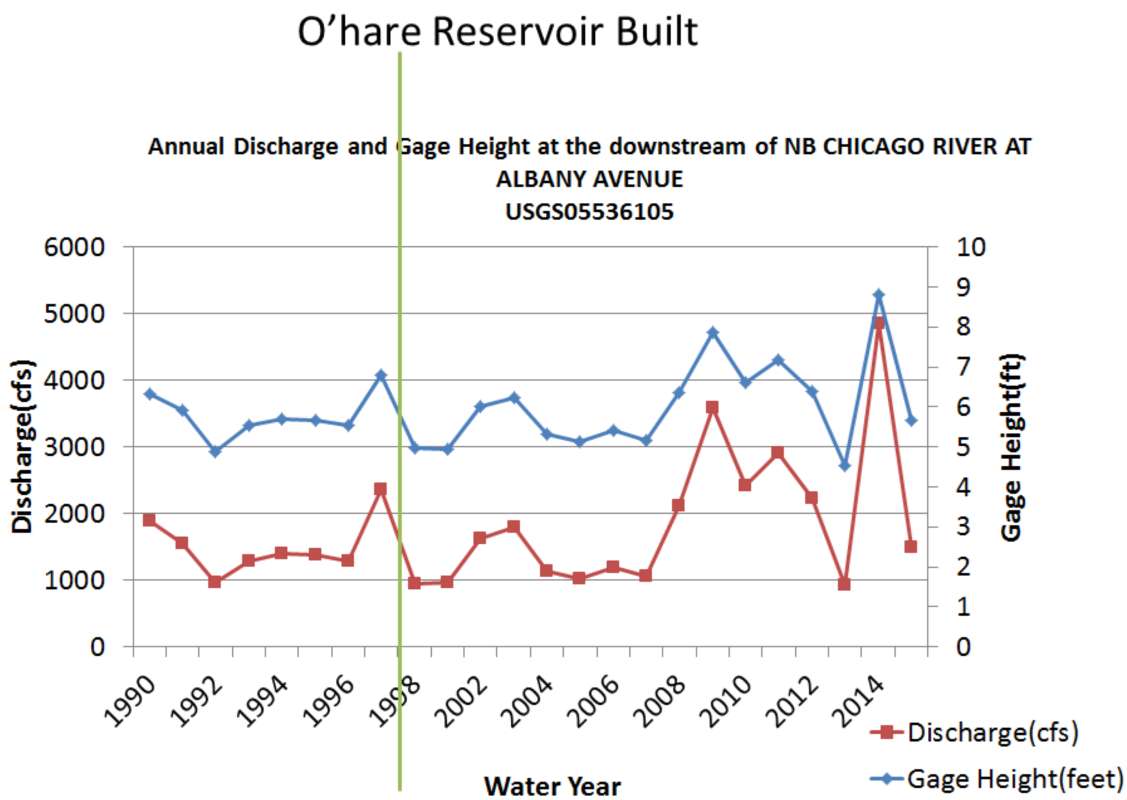


Figure 7: Annual Discharge and Gage Height at the downstream of NB CHICAGO RIVER AT ALBANY AVENUE

Figure 7 shows the discharge and gage height at USGS05536105 which is the top one connected to O'Hare reservoir and this gage has the most relevant and enough data to analyze. Discharge and Gage height have very similar pattern each other. Typically, the relationship between stream flow discharge and gage height is not linear. Since stream banks in natural streams do not look like man-made bank such as rectangular, the flow between height 3 and 4 would not be same as that of between height 3 and 2. On this case, the relationship between discharge and gage height level is linearly correlated in early

1990's rather than present, but it still can be said they are in linear connection. According to Metropolitan Water Reclamation District of Greater Chicago (MWRD), O'Hare reservoir was completely built in 1998 with 350 million gallon of capacity and 250 million dollars of flood damage reduction.

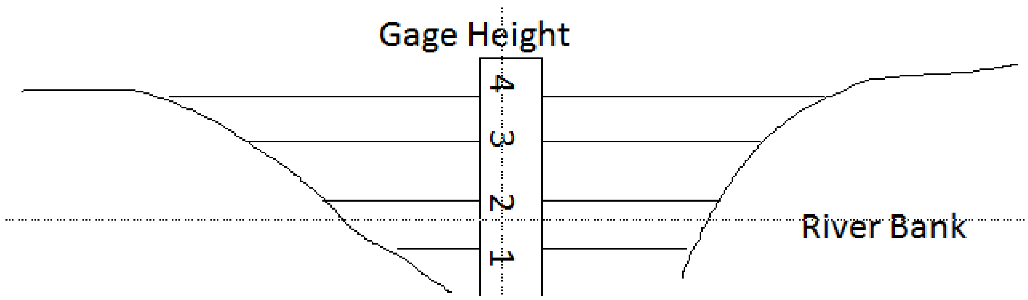


Figure 8: Relationship between gage height and streamflow (Source: http://cals.arizona.edu/watershedsteward/resources/module/Stream/stream_dataavail_pg1.htm)

Based on the first goal of TARP, gage height should be decreased after completion of reservoir. Refer Figure, from 1998, gage height steadily balanced for about 10 years after completion. The graph was fluctuating after 2008; it may be because of sudden development of urban and suburban area and incensement of impervious area.

Table 2: Annual Discharge and Gage Height at the downstream of NB CHICAGO RIVER AT ALBANY AVENUE

	Gage Height(feet)	Discharge(cfs)
1990	6.34	1890
1991	5.92	1540
1992	4.89	965
1993	5.54	1290
1994	5.71	1400
1995	5.68	1370
1996	5.55	1280
1997	6.81	2360
1998	4.98	954
2001	4.95	963
2002	6.01	1620

2003	6.24	1800
2004	5.31	1130
2005	5.12	1030
2006	5.43	1200
2007	5.16	1060
2008	6.36	2110
2009	7.86	3580
2010	6.62	2420
2011	7.17	2910
2012	6.39	2230
2013	4.53	930
2014	8.81	4850
2015	5.66	1490.00

- USGS05536118 N.B. Chicago River at Grand Ave at Chicago, IL

Moving to the next reservoir, McCook Reservoir; it is nearly on it final stage since an original plan made its completion in 2017 with 10 billion gallon of capacity and 114 million dollars of flood damage reduction. McCook reservoir is correlated to gage number USGS 05536118 N.B. Chicago River at Grand Ave at Chicago, IL and its gage height and discharge are reflected in Figure 9. The gage has been started a recording from 2004 for discharge and gage height from 2006; therefore, there is not enough data to interpret a relationship between USGS stream discharge and the presence of big and deep reservoir. Discharge maintained a stable level about 600 cfs and a noticeable point is that the discharge in 2008 is about 650 cfs and the gage height recorded negative -2.3 feet. It can be said for big flow, the gage height can be sustained stabilized level thanks to a new reservoir.

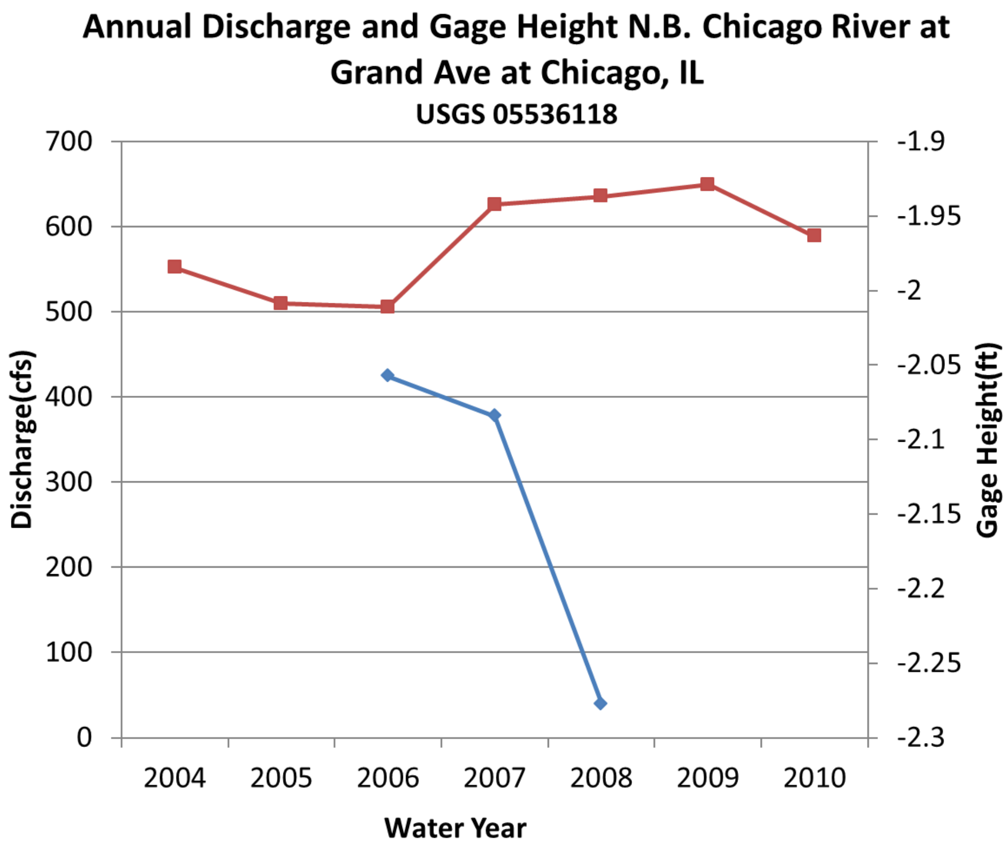


Figure 9: Annual Discharge and Gage Height at the downstream of N.B. Chicago River at Grand Ave at Chicago, IL

Table 3: Annual Discharge and Gage Height at the downstream of N.B. Chicago River at Grand Ave at Chicago, IL

	Gage Height(ft)	Discharge (cfs)
2005		510.4
2006	-2.057	506.0
2007	-2.084	626.5
2008	-2.277	636.4
2009		650.2
2010		589.4

- USGS 05536358 CALUMET R BLW OBRIEN LOCK AND DAM AT CHICAGO, IL

The calumet river and calumet dam are located at the south of Chicago, there are two USGS station, USGS 05536358 and USGS 04092500 Wolf Lake at Chicago, IL; but there is no data at at all at USGS 04092500. At USGS 05536358, there is not enough data to clarify is TARP working or not. Gage height was not available at this gage.

Table 4: Annual Discharge at the downstream of USGS 05536358 Calumet R Blw Obrien Lock and Dam at Chicago, IL

	Discharge(CFS)
1997	191
1998	190.8
1999	169.2
2000	139.7
2001	116.9
2002	88.8
2003	95.4

As shown in Figure 10, it is clear that the discharge was gradually decreasing before USGS stopped gaging. Thornton reservoir connected to this USGS gage is already completed as they proposed in the initial report with 11 billion gallon of capacity and 40 million dollars of flood damage reduction.

Figure 11 depicts Chicago area waterway system provided by MWRD and I deducted complicated layers and simplified. Blue boxes are waste water treatment plant (WWTP). Red cross dots are control structures such as pipe, tunnel and dropshaft. White cross dots are pump station and it is at the same location as USGS stream gage stations.

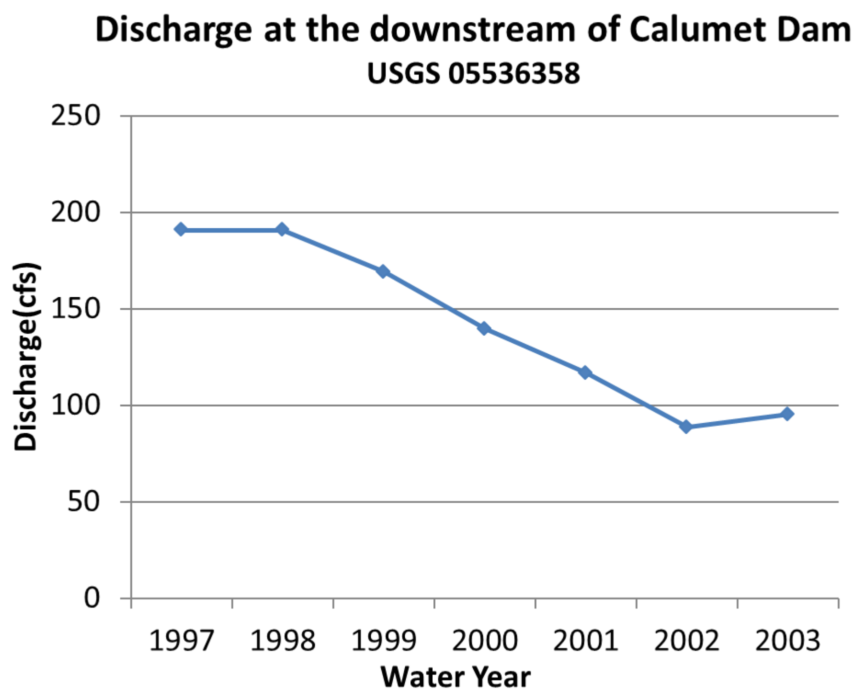


Figure 10: Annual Discharge at the downstream of USGS 05536358 Calumet R Blw Obrien Lock and Dam at Chicago, IL

2. *Lumped InfoSWMM Model*

To measure inflow into the entire TARP system for each dropshaft, InfoSWMM (MWHsoft, 2005) is creating a lumped hydrology model for dropshaft by dropshaft. As I delineated the service area where I would like to model through ArcGIS databases, lumped InfoSWMM models will be created for all dropshaft in the service area.

Therefore, it will be able to compare inflows from USGS and InfoSWMM in the specified area to figure out how much flow is captured after the construction. Inflow data from a USGS gage is hourly precipitation data. I was one of research assistants in this project in the University of Illinois in Urbana-Champaign where I graduated from.

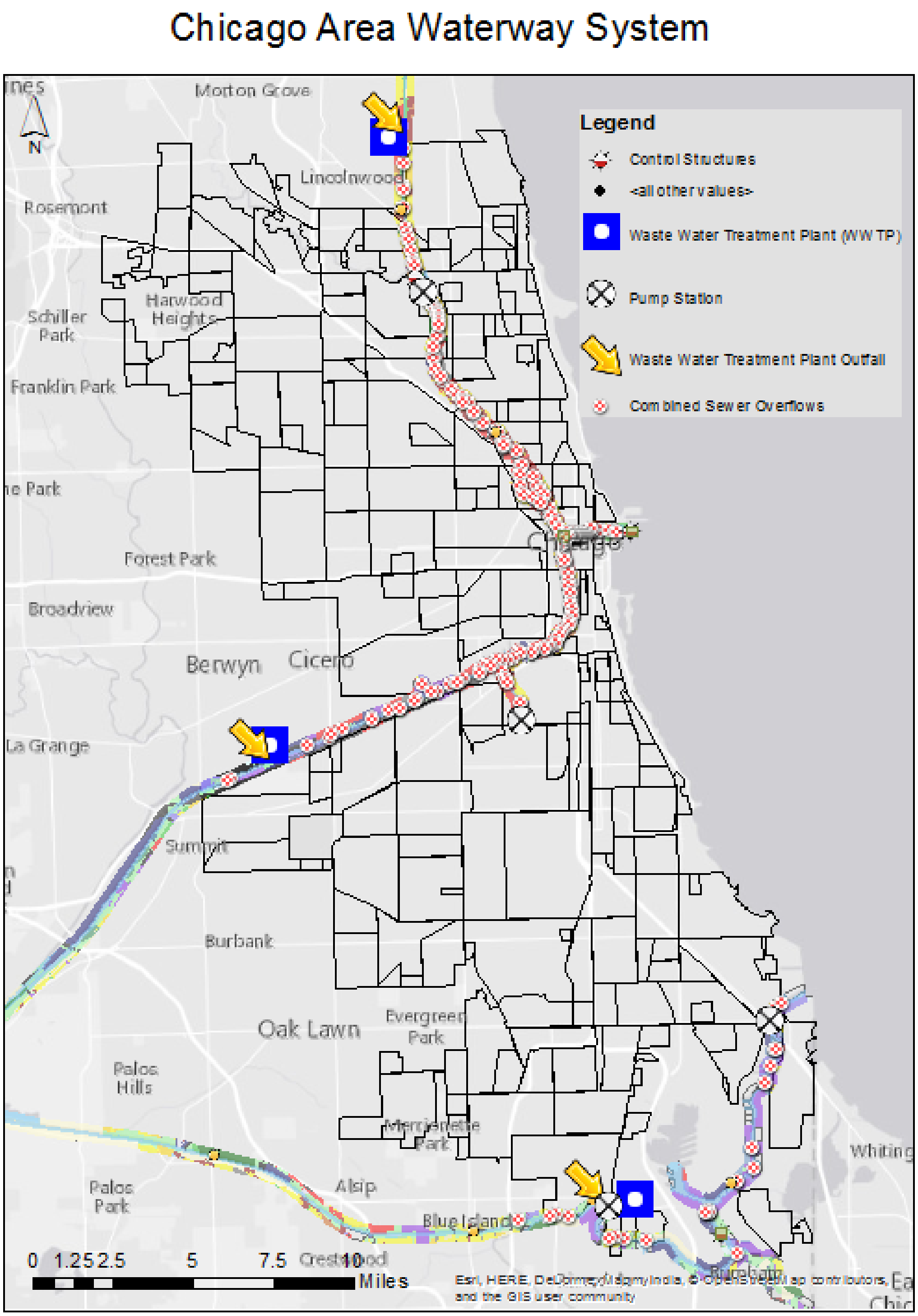


Figure 11: Chicago Area Waterway System

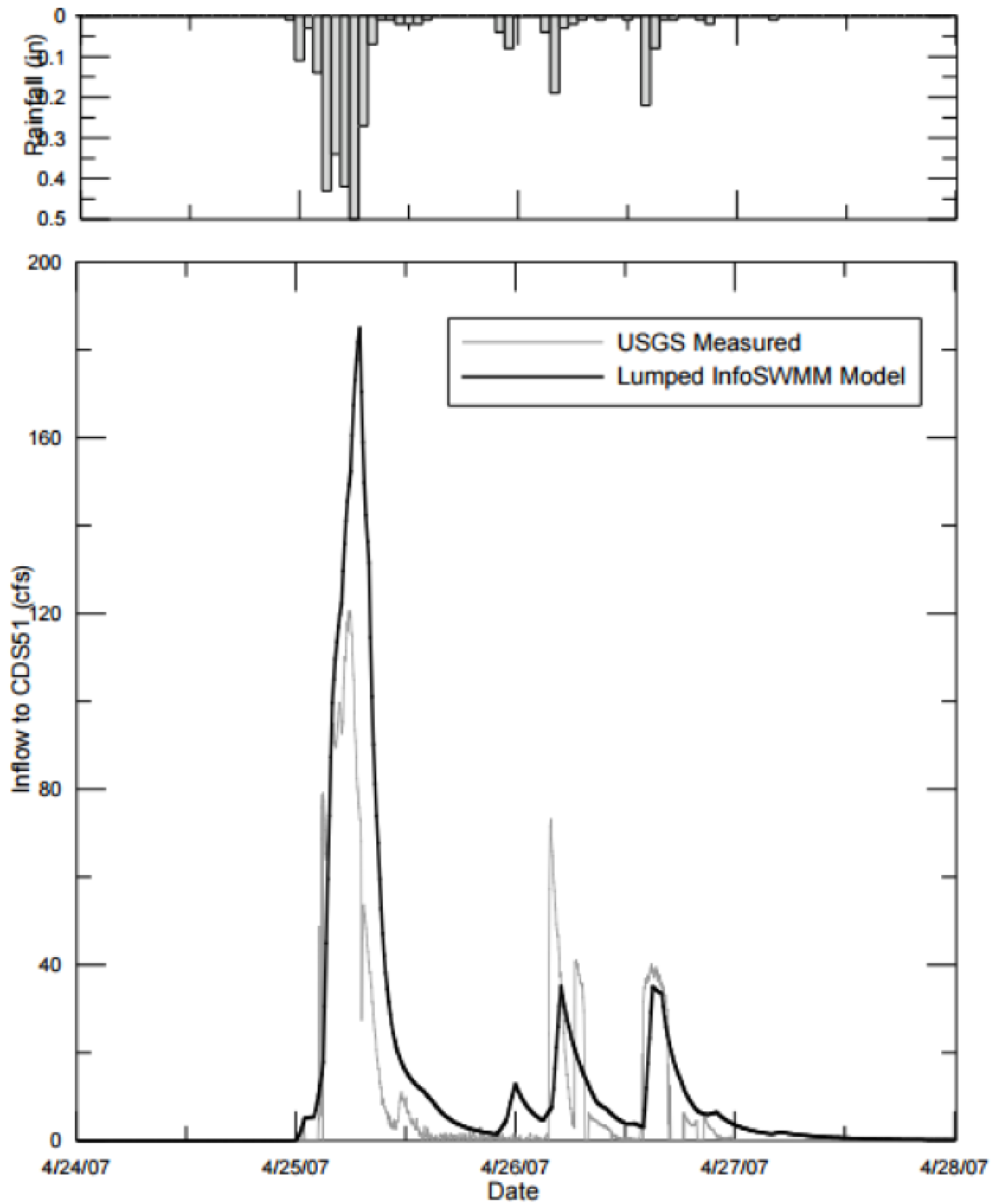


Figure 12: Simulation results for storm of April 25-27, 2007 at CDS-51 (A.R. Schmidt et al. 2009)

I collected relevant data for a dropshaft in TARP system and simulated sort of similar things in EPA SWMM and InfoSWMM. Figure 12 illustrates simulation results for storm of April 25-27 in 2007 at CDS-51 in the Village of Dolton, a southern suburb of Chicago. CDS-51 is one of the combined sewer networks which serve the Calumet TARP system. InfoSWMM made a great expectation in comparison with observed precipitation data in terms of its pattern. However, on April 25th, InfoSWMM model overestimates inflow to CDS51 than measured data from USGS. These errors come from the assumption that the precipitation at near USGS gauges is uniform over the catchment(A.R. Schmidt et al., 2009). In proposal and progress reports which I submitted, I wanted to model more storm and dropshaft but the data accessibility was highly limited to related researchers so it was not able to access enough data related to which dropshaft is influencing which catchment.

Conclusion

Because of limited data accessibility and its unique characteristic of waterway system in Chicago (most of the drainage system is located underground), it was not fully developed and analyzed as proposed to evaluate TARP eventually works for Chicago and its suburban communities. However, it is found that the gage heights near built reservoirs are maintained as stabilized level compare with before the project. Tunnel and Reservoir Plan had been established in early 1970's. It is about 50-year-old project that is vulnerable to climate change such as heavy rainfall with high intensity and incensement of impervious area with an accelerated development in Chicago and suburban area. Near the completion of the plan, the precipitation in Chicago hit the record during 120 years and there still is heavy rainfall and risk of flooding even its presence of deep and big and huge reservoirs. Therefore, as we focused on the physical solution which is the reservoir, it would be moved a focus to the fundamental factors which is the increment of impervious area in cities: Best Management Practices. As US EPA illustrated, BMPs is one of water pollution control type and stormwater BMPs are especially focused on techniques and management to control the quantity and improve the quality of stormwater (Best Management Practices (BMPs), 2013). Installation of green roof on the roof top of the buildings was supported at “Water Agenda” in 2003 (Chicago's Water Agenda 2003, 2003) and “Climate Action Plan” in 2008 (Johnston, et al., 2008) and Mayor Rahm Emanuel took this idea in “Sustainable Chicago 2015” (Malich, et al., 2012) project which replaces 1.5 million square feet of impervious area to pervious area.

As there are so many projects to reduce the risk of flood in Chicago area, there is a great solution to resolve the recurrence problem for more than 100 years in Chicago. The solution would not be the single but combined one with drainage, pipe and reservoir system underground, water quality control, climate change control and a policy.

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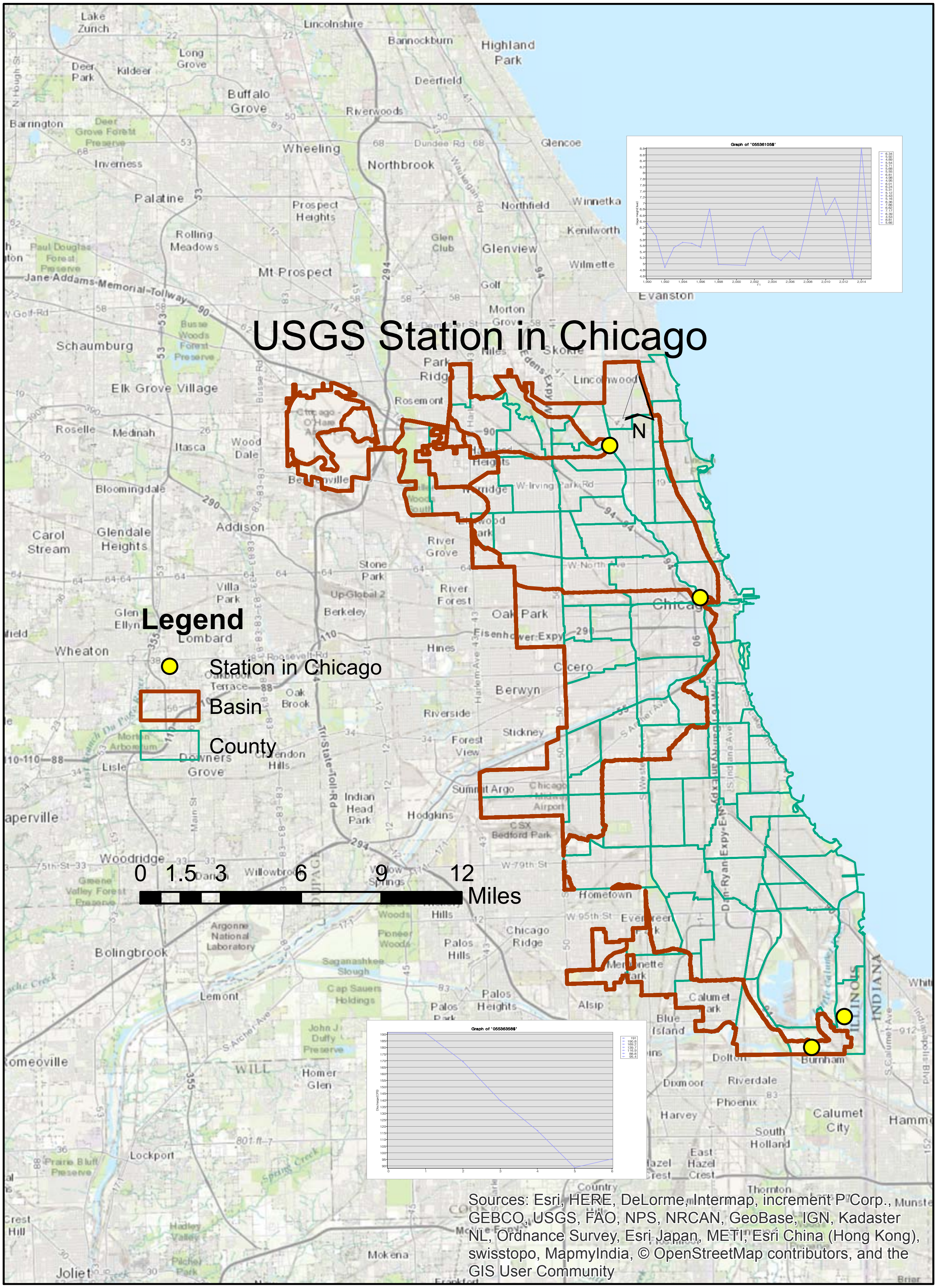
USGS Station in Chicago
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Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community