Flooding Resilience Plan for Bus Operations

Appendix B: Task 3 Technical Memorandum: Future Climate Change Impacts on Flooding

Prepared for the Regional Transportation Authority
of Northeast Illinois

March 30, 2018

March 2018

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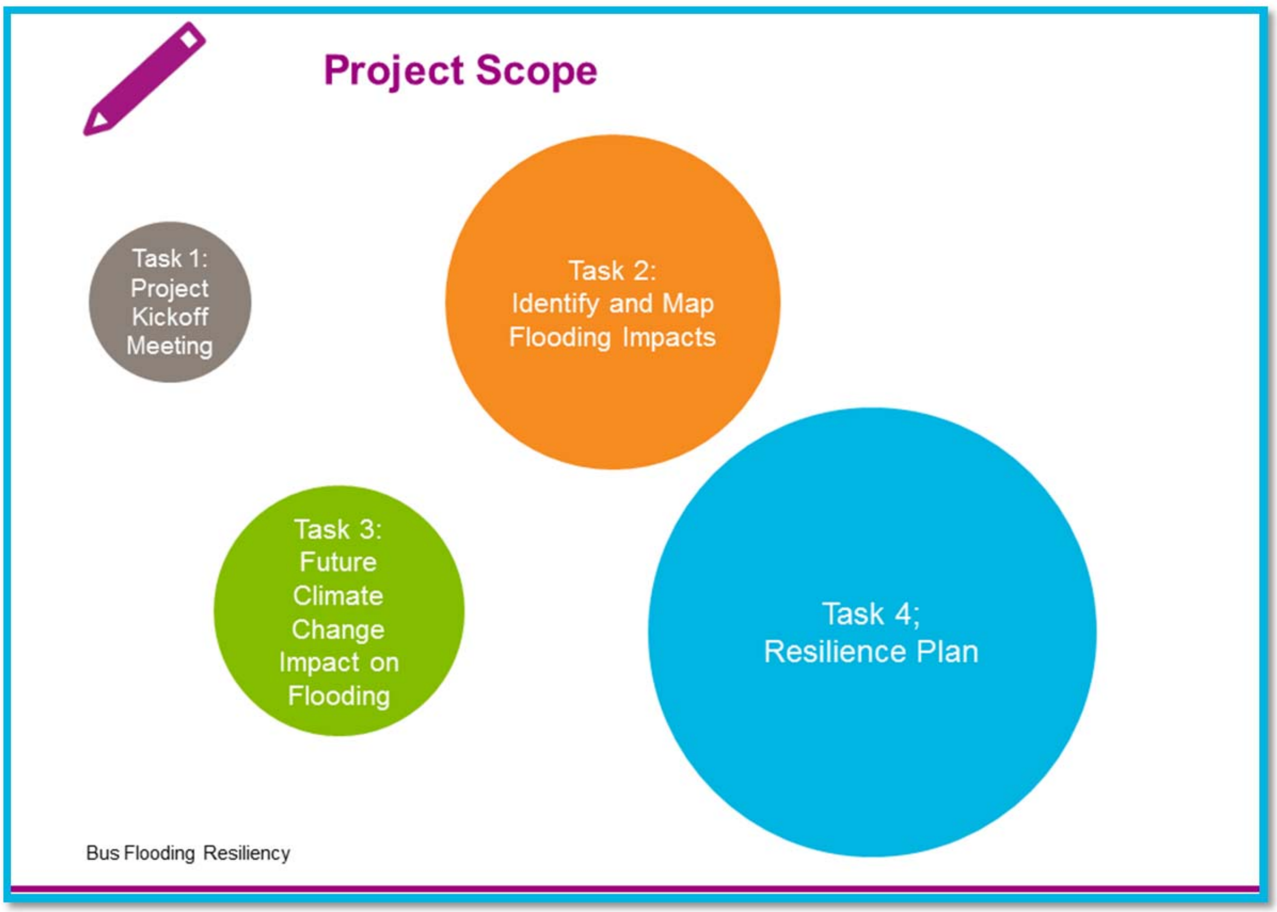
1. Introduction

In Fall 2015, as a continuation of its Green Transit program, the Regional Transportation Authority (RTA), initiated a project to prepare a bus route flooding resilience plan for the RTA region composed of its six-county jurisdiction in northeastern Illinois, including Cook, DuPage, Kane, Lake, McHenry, and Will Counties. The objective of this project is to identify CTA and Pace bus routes prone to flooding during both average rain events and extreme weather events. Aside from hampering citizens' mobility, such flooding events can have negative impacts on operating costs and ridership revenues. The project is intended to develop recommendations to address flooding issues and reroute service during flooding.

The scope of the study, which kicked off in Summer 2016, is organized into four major work tasks:

1. Initiate Project
2. Identify and Map Flooding Impacts
3. Assess Future Climate Change Impacts on Flooding
4. Prepare a Resilience Plan



March 2018

This Technical Memorandum summarizes the work of **Task 3**, during which the project team examined the effects of changing climate patterns on the flood risk landscape in the region. Research conducted in 2008 for the Chicago Climate Action Plan indicates that increases in winter and spring precipitation are likely, with projected increases of about 10 percent by the year 2050, and of about 20 to 30 percent by 2099. At present, even minor storms are enough to overwhelm the stormwater system of some parts of the region, and these are expected to occur even more often. For example, today's 2-year storm event is expected to occur every year by mid-century, or phrased differently, an event that has a 50% chance of being equaled or exceeded in any given year is expected to have a 100% chance by mid-century. Additionally, the intensity of heavy precipitation events (5-, 10-, and 25-year storms) is likely to continue to increase. Effects of these trends will vary across the region according to watershed and sub-watershed hydrological patterns. With input from county and local stormwater management departments, the project team assesses whether these forecasted increases are likely to worsen risk conditions for the bus routes identified in Task 2.

2. Future Climate Change Impact on Flooding

2.1 Climate Studies in the Region

2.1.1 Chicago Climate Action Plan

The Chicago Climate Action Plan was an important precursor to the RTA's Green Transit and Resilience planning efforts. It looks to both the past and the future before laying out its action steps for a more resilient metropolis.

According to historical records, the frequency of heavy storms has doubled since the 1970s, with more of the precipitation falling as rain rather than snow. There is less ice coverage on Lake Michigan and area lakes and less snowpack in the winter. Temperatures have risen by 2.6°F since 1980—especially winters, which are on average are almost 4°F warmer.

To understand how a local area will be affected by climate change in the future, climate scientists take global circulation models (GCM) and downscale them to a finer resolution at the regional level to predict temperature and precipitation levels before running that data through hydrological and hydraulic models to determine where the water is likely to go. An example of this downscaling is shown in **Figure 1**. Given the uncertainty of the field, several datasets and models (e.g., GDFL, PCM, CCSM3) engineered by different research agencies across the world are used and their results compared to find the more likely outcome. To reflect the different possible futures in terms of emission reduction policies, population growth, economic growth, etc., it is important to run the models under high and low emissions scenarios (e.g., A1 and B1). By combining this forecasting of future climate conditions with current data on severe weather events, it is possible to gain a more realistic understanding on what kind of weather to expect and where.

Figure 1: Sample Downscaled Climate Projections

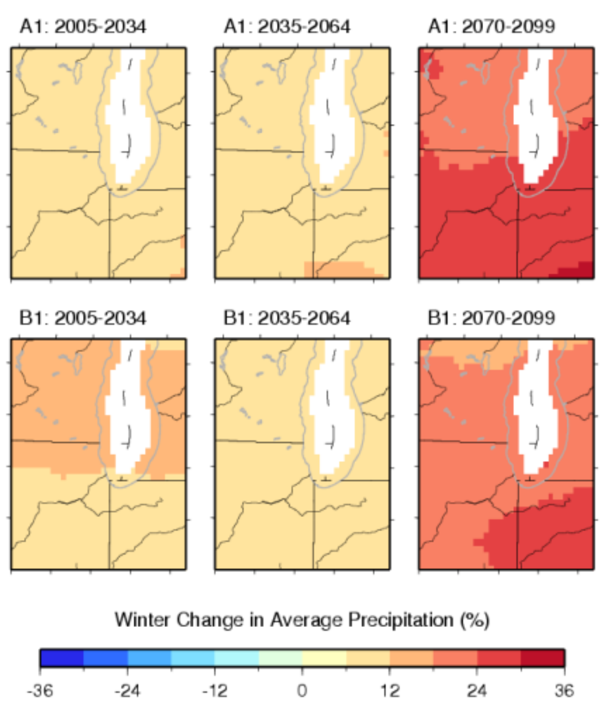


Image source: Chicago Climate Change Action Plan, p. 4.

The federal government and research organizations like the World Climate Research Programme provide data and tools to assist transportation agencies in generating local climate change projections and interpreting their effects. For example, the US DOT provides the Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool and the Vulnerability Assessment Scoring Tool, which translate downscaled climate model data into more relatable terms for non-experts and helps them to assess vulnerability to extreme weather events. Local and regional agencies like the Illinois State Water Survey also do their own analyses. In their analysis that agency found that some of the global climate change data sources underestimated precipitation extremes when downscaled to the regional level (see below). The U.S. Global Change Research Program has developed climate information that is relevant at broad geographical scales and can be used by local agencies or project teams. Federal agencies like NOAA, USGS, and USACE have data, modeling, historical weather data, and future climate predictions that local agencies can draw from.[1]

The climate forecast projections used in the Chicago Climate Action Plan come from three different global climate models (GDFL, HadCM3, and PCM), which are then downscaled to the Chicago region using long-term historical records and advanced statistical techniques. These models are run using two different emissions scenarios—low and high—to reflect different potential futures based on the climate change mitigation policies espoused and undertaken in the coming years. The resulting six simulations generate climate projections through 2100.

These temperature and precipitation rates are then input into hydrological models to simulate how much of the water will be absorbed into the earth, evaporated into the sky, or runoff into waterways (e.g., evapotranspiration, runoff generation, soil infiltration and drainage, snowpack accumulation, snowmelt). These results, in turn, are then routed through stream networks using a hydraulic model to determine where that water will go and where it will accumulate.

According to this analysis by climate science experts and water resource engineers, the Chicago region can expect:

- Average annual temperatures 3-4°F (low emissions) or 7-8°F (high emissions) warmer, and up to 10°F warmer during the summers
- Summers that feel similar to current Mobile, AL, with heat indexes averaging 105°F (high emissions scenario); under low emissions, more like Atlanta, GA, with heat indexes around 94°F
- More heatwaves, higher heat indexes due to increased humidity, fewer cold spells, decreased air quality, more frequent vector- and water-borne diseases
- 10% more winter and spring precipitation by 2050, and 20-30% more by 2100 (both high and low emissions)
- More heavy rainfall events of 2.5 inches or more in 24-hour period—i.e., those associated with flooding
- Increased evapotranspiration, increased runoff, and an increase in peak flow in Illinois River

A comparison with previous climate change impact projects conducted for the Midwest and Great Lakes region from 2000 and 2003 shows that this analysis confirms these earlier projections.

These types of impacts—higher temperatures, greater precipitation in heavier rain events—will have a major impact on Chicago's infrastructure. Emissions levels will be significant here: under the high-emissions scenario, the projected costs of adaptation for government are nearly four times higher than the low-emissions scenario. Aside from the direct costs of increased maintenance and replacement of hard infrastructure like roadways, bridges, fleet vehicles, etc., there will be less tangible costs such public health problems arising from poor air quality and temperature extremes, more frequent disease outbreaks, crop damage from intense storm events or summer droughts, among other consequences of climate change.

The Chicago Climate Change Action Plan looks at the costs of adapting to more sustainable practices that would reduce emissions and thus climate impacts, and finds that sustainable practices (such as those that would result in resource efficiencies) could generate $400 million to $1.2 billion in savings each year by 2020. It also quantifies the increase in green jobs in order to achieve the plan's goals, as well as the jobs that would be created by achieving the goals. More detail on action steps for climate change resilience in the Chicago region can be found in **Appendix C: Best Practices**.

[1] As a primer to the subject, the FHWA published *Regional Climate Change Effects: Useful Information for Transportation Agencies* (2010), which provides basic information on climate change effects in the near, medium, and long term by region, as well as how this information can be applied to transportation planning, operations, and asset management. The analysis relies on USGCRP climate impact data and projections using the CMIP tool. For further discussion of climate change data, analyses, and applications, see the 2011 FHWA report, *The Use of Climate Information in Vulnerability Assessments.*

2.1.2 Illinois State Water Survey

A 2016 Illinois State Water Survey report, "Communicating the Impacts of Potential Future Climate Change on the Expected Frequency of Extreme Rainfall Events in Cook County, Illinois" sought to design a framework to translate future climate scenarios into something that local-level engineers and planners can use to quantify the impact of climate change. The output can then be used to inform and plan adaptive strategies for floodplain management. The research found that two of the three data sources (WCRP and ORNL) commonly used for climate change modeling considerably underestimated rainwater extremes in Cook County.

2.1.3 Center for Neighborhood Technology

In 2014, the Center for Neighborhood Technology examined the economic costs of urban flooding in Cook County. This report, "The Prevalence and Cost of Urban Flooding," found that between 2007 and 2011, 181,000 insurance claims added up to $773 million in damages, and there was no correlation between damage payouts and floodplains, either in number or value of claims. One pattern that was noticeable was that places that had flooded once were likely to flood again—and soon. Of the 115 survey respondents, 70% said they had been flooded three times or more in the last five years, and 20% had been flooded ten times or more.

2.2 Analysis of Future Areas of Risk for Bus Operations

As detailed in previous chapters, the process to identify bus routes of concern used a range of environmental, socio-economic and transit data to flag risks and areas of focus in the present period. In preparing mitigation strategies, it is prudent to look ahead to the extent possible to anticipate future conditions to avoid recommendations that might be short-lived or less relevant under future scenarios of climate change.

2.2.1 Input data

The analysis in this study to understand the potential implications of future climate change, and more-frequent, more severe storm events in the future was divided into two work streams to address the different root causes of flooding in urban vs. suburban / exurban contexts.

Analysis of urban flooding – with its origins typically in the built environment and ability of infrastructure to manage large amounts of stormwater – included the following base data:

- Locations of bus service interruption and route-level comments on typical flood problems reported by CTA staff
- Locations of bus service interruption and route-level comments on typical flood problems reported by Pace staff
- Road closures due to flooding reported by Cook County Department of Transportation and Highways
- Locations of viaducts (and annotation of "problematic" or "flood-prone" viaducts) by CDOT, CTA and Pace
- City of Chicago 311 reported flood calls, including water on pavement and flooded viaducts

Figure 2: OEMC Street Flood Calls, Density of CTA Flood Reports, CDOT Viaducts, and CTA Scenario E Routes

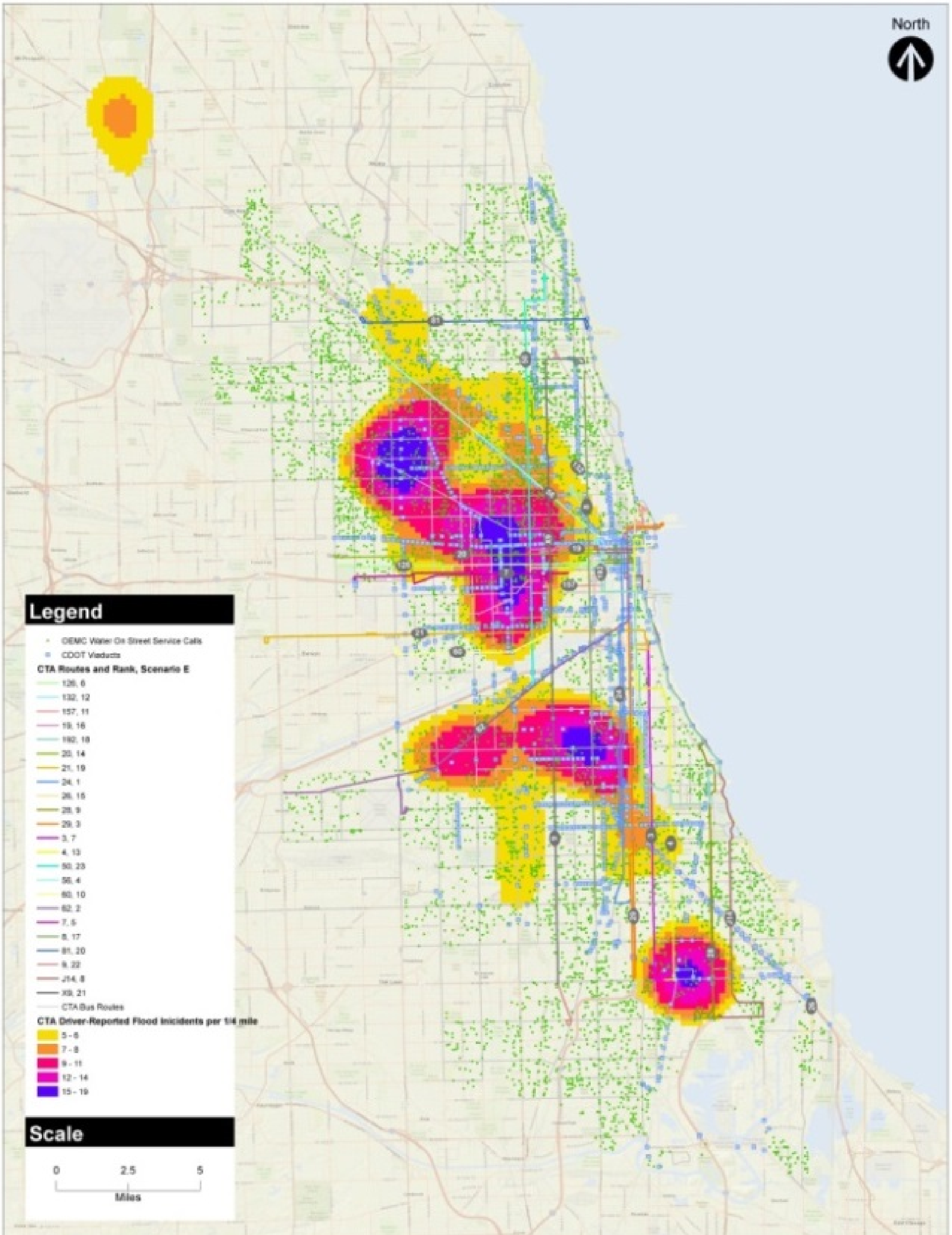


Figure 3: CDOT Viaducts, OEMC Viaduct Flood Calls, CTA Flood Reports, and CTA Scenario E Routes

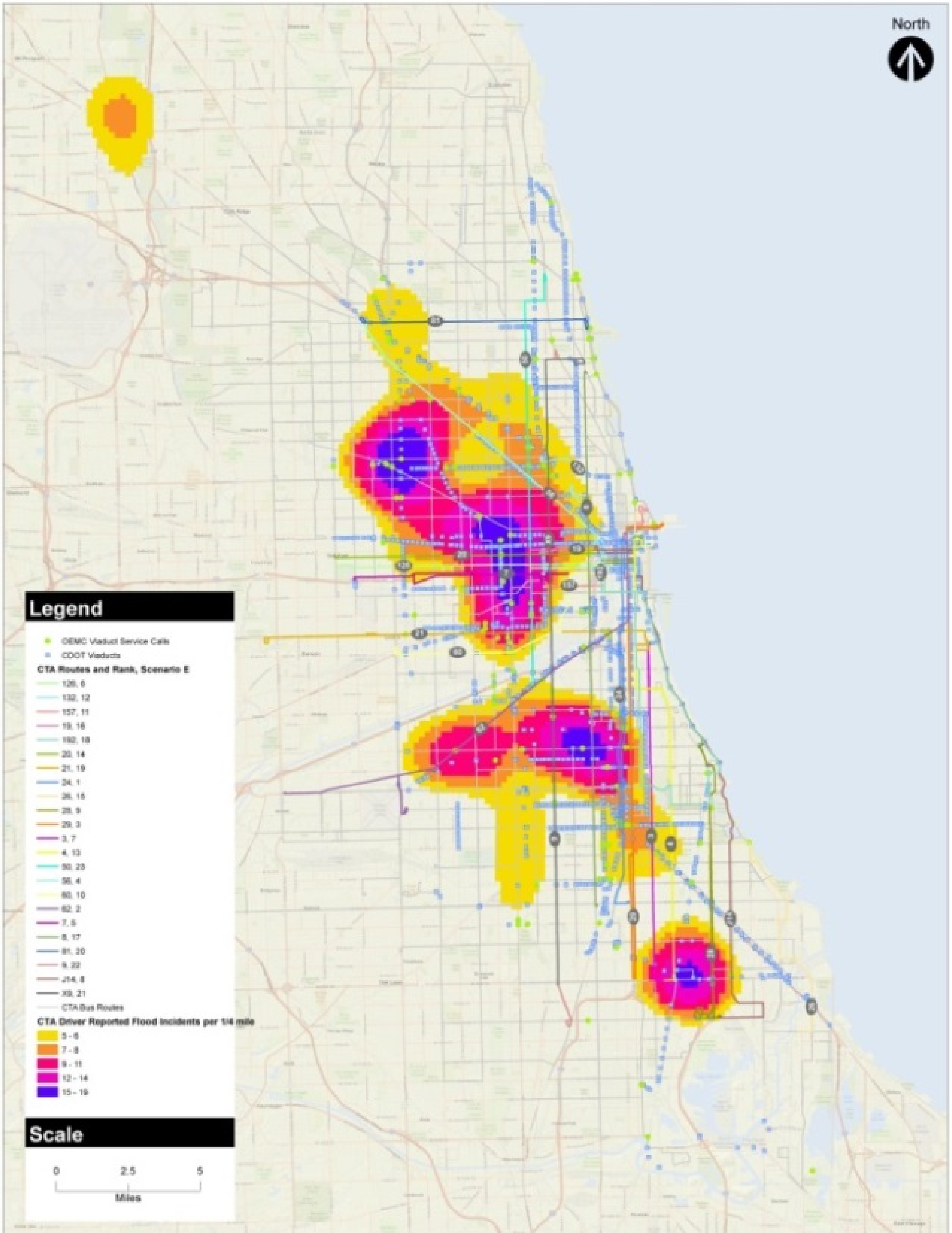


Figure 4: CTA Routes with Greatest OEMC 3-1-1 Calls on Street & Viaduct Flooding

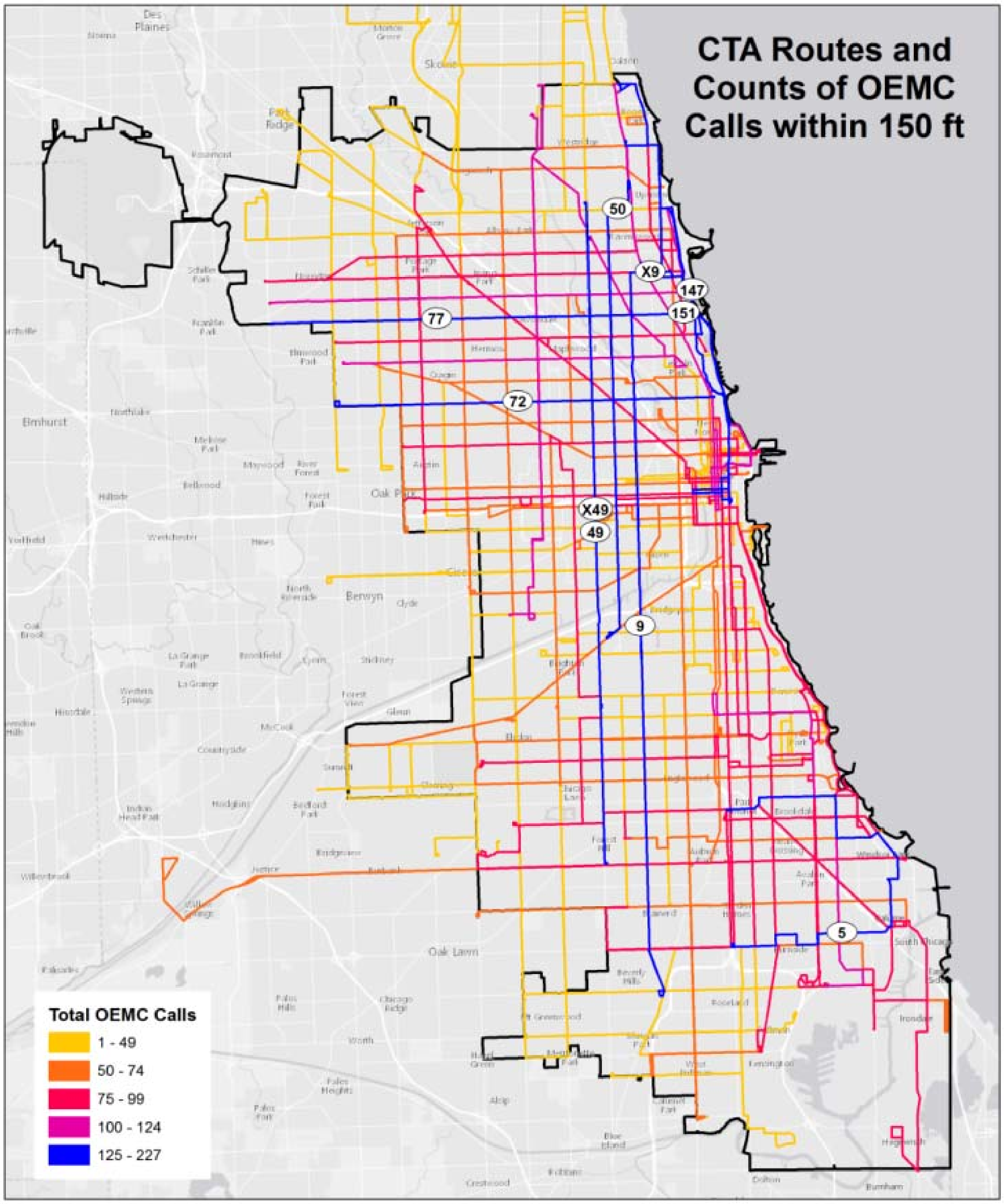
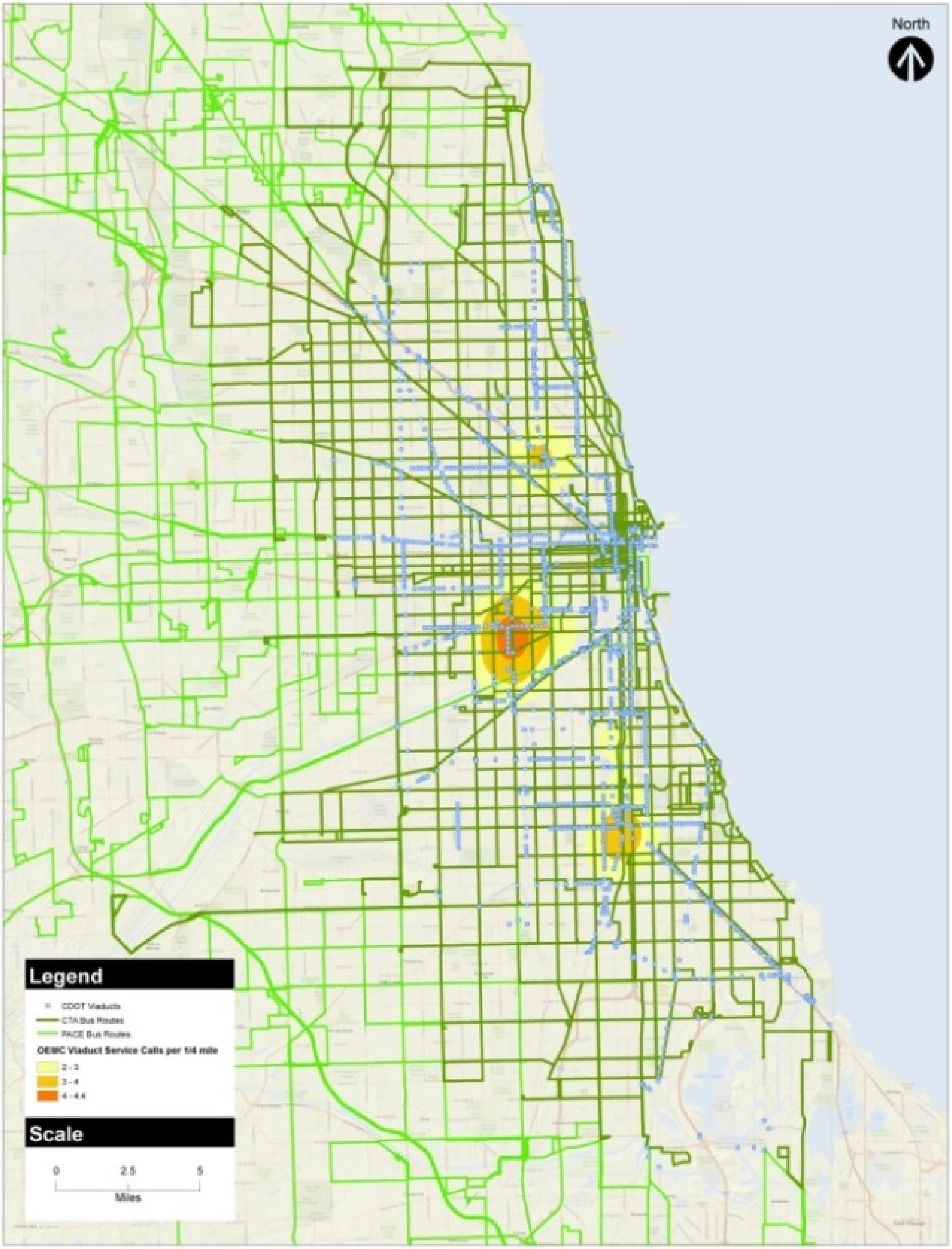


Figure 5: All Bus Routes, CDOT Viaducts and OEMC Viaduct Flood Calls



Analysis of riverine flooding – with its origins typically in overbanking of water bodies (rivers, streams, reservoirs, etc.) from large amounts of stormwater – are more often located in suburban / exurban areas and included the following base data:

- Locations of bus service interruption and route-level comments on typical flood problems reported by CTA staff
- Locations of bus service interruption and route-level comments on typical flood problems reported by Pace staff
- FEMA 100-year and 500-year floodplain boundaries
- Local updates on floodplain boundaries / inundation areas from counties (Cook/MWRD, DuPage, Will)

2.2.2 Methods for evaluating climate change data and potential future flooding patterns

2.2.2.1 Rainfall Frequency Adjustment for Climate Change

Stormwater and water resource engineers and scientists on this project team evaluated the potential increases in rainfall in the RTA service area by reviewing the climate change scenarios from the Chicago Area Climate Action Plan defined in the previous section. The increases for future climate change scenarios B1, A1B, and A2 were averaged and plotted as 2-, 10-, and 100-year adjustments on log-log paper to determine adjustments for other types of storms. These adjustments were then added to the Illinois State Water Survey's Bulletin 70 24-hr rainfall amounts, which likewise were plotted on log-log paper. Team members then interpolated existing and future rainfall frequency curves to identify the equivalent storm frequency for future rainfall events at mid-century 2017 and late-century 2017.

The term "Storm Recurrence Interval" refers to the chance or probability that a storm of a certain magnitude may occur or be exceeded in a given year. For example, a "100-year storm" has a 1 in 100 chance of occurring in any given year, or 1% chance (called the "Annual Exceedance Probability"). It does not mean that such a storm only occurs once every 100 years, and once happened, won't happen again in the same 100-year period.

Table 1: Mid-Century Adjusted Rainfall

Bulletin 70 Current Storm Recurrence Interval (Years)	Current Annual Exceedance Probability† (%)	Bulletin 70 24-hr Rainfall	ISWS Contract Report 2016-05 Mid Century 24-hr Rainfall Adjustment (in)	Adjusted Rainfall (in)	Equivalent Bulletin 70 Future Storm Recurrence Interval (Years)
1	100%	2.51	0.46	2.97	1.9
2	50%	3.04	0.55	3.59	4.3
5	20%	3.80	0.70	4.50	11.0
10	10%	4.47	0.83	5.30	24.0
25	4%	5.51	0.83	6.34	44.0
50	2%	6.46	0.83	7.29	85.0
100	1%	7.58	0.83	8.41	150.0
500*	0.2%	11.10	0.83	11.93	620.0

*Extrapolated

†Percent chance of occurrence in any given year; also called Annual Exceedance Probability (AEP) the percent chance storm is equaled or exceeded in any given year
*** Extrapolated*
Source: Illinois State Water Survey Contract Report 2016-05; ISWS Bulletin 70, AECOM and 2IM Group

Table 2: Late-Century Adjusted Rainfall

Bulletin 70 Current Storm Recurrence Interval (Years)	Current Annual Exceedance Probability (%)	Bulletin 70 24-hr Rainfall	ISWS Contract Report 2016-05 Mid Century 24-hr Rainfall Adjustment (in)	Adjusted Rainfall (in)	Equivalent Bulletin 70 Future Storm Recurrence Interval (Years)
1	100%	2.51	0.72	3.29	2.5
2	50%	3.04	0.83	3.87	5.4
5	20%	3.80	1.00	4.80	14
10	10%	4.47	1.15	5.62	28
25	4%	5.51	1.27	6.78	60
50	2%	6.46	1.38	7.84	110
100	1%	7.58	1.50	9.08	240
500*	0.2%	11.10	1.77	12.87	915

*Extrapolated

Source: Illinois State Water Survey Contract Report 2016-05; ISWS Bulletin 70, AECOM and 2IM Group

This generalized modeling of anticipated rainfall suggests storms of greater severity may occur more frequently in the future. That is….

For severe storms:

A 100-year storm mid-century could be like today's 150-year storm
A 100-year storm late-century could be like today's 240-year storm

For moderate storms:

A 5-year storm mid-century could be like today's 11-year storm
A 5-year storm late-century could be like today's 14-year storm

A 1-year storm mid-century could be like today's 1.9-year storm
A 1-year storm late-century could be like today's 2.5-year storm

2.2.2.2 Urban Flooding Methodology

To analyze the potential impact of future climate change and rainfall events of increasing severity and frequency over the next century on urban flooding patterns, water resource and stormwater specialists correlated rainfall data from recent storm events with recorded flood incidents from CTA and OEMC. A subset of recent storm events of varying frequencies were selected from the period 2013-2016 when CTA recorded flood incidents and OEMC 311 call data were available on the same dates. This data is presented in **Table 3** and **Table 4** below.

Table 3: Rain Storm Frequency – Analysis of Subset of Storms

Rain Storm Frequency									
	Storm Gage								
Storm Event	Midway			O'Hare			Palwaukee		
	Rain (in)	Duration (hrs)	Rec Interval	Rain (in)	Duration (hrs)	Rec Interval	Rain (in)	Duration (hrs)	Rec Interval
Minor Storms (100% to 500% chance in any given year)									
April 18, 2013	1	4	2 mo					nm	
April 19, 2015		nm		1.28	6	3.5 mo			
December 23, 2015	0.7	1	2.5 mo	0.7	1	3.25 mo	0.7	1	2.5 mo
February 2, 2016	2	10	2 mo	0.8	3	2 mo	0.8	3	2 mo
March 24, 2016	0.9	7	2 mo	0.9	7	2 mo	0.9	7	2 mo
January 17, 2017	1.2	24	2 mo	1.2	24	2 mo	1.2	24	2 mo
February 7, 2017	0.5	1	2 mo	0.5	1	2 mo		nm	
Moderate Storms (e.g., 1 Year Event (50% to 100% chance in any given year))									
April 19, 2015		nm					1.7	6	9 mo
June 15, 2015	1.47	5	1	2.5	12	2 yr		nm	
Severe Storms (e.g., 25 Year Event (5% chance in any given year))									
April 18, 2013				5.5	2.4	25 yr			

Table 4: Urban Rainfall Data Analysis - Selection of Storms

Storm Date	Frequency	Duration	Gauge Level	311 Calls	311 Call Density
Feb 7, 2017	<2-month	1hr	0.5"	249	1.1
January 16-17, 2017	<2-month	24hr	1.2"	374	1.6
March 24, 2016	<2-month	25hr	1.0"	241	1.0
June 15-16, 2015	2-month	11hr	1.2"	252	1.8
December 23, 2015	2.5-month	1hr	0.7"	213	0.9
Feb 7, 2017	2- to 6-month	1hr		50	3.7
April 9, 2015	4-month	6hr	1.3"	254	1.2
Feb 2-3, 2016	6- to 9-month	10hr	2"	149	2.8
July 23-24, 2016	1-yr	7hr	2.0"	166	0.8
Sept 17-19, 2015	2-yr	24hr	3.0"	202	0.9
June 15-16, 2015	2-yr	11hr	2.5"	297	3.1
July 23-24, 2016	5-yr	7hr	2.5"	5	0.9
April 17-18, 2013	5-yr	20hr	3.5"	179	2.0
April 17-18, 2013	15-yr	16hr	4.0"	381	4.0
April 17-18, 2013	25-yr	24hr	5.5"	257	4.9

Rainfall levels and durations of storm at three regional gages were analyzed to identify storm type. Data from the three regional gages at O'Hare, Midway, and Palwaukee airports were used because these gages provide hourly measurements, whereas other gages across the region may provide geographic breadth but do not generate data on an hourly basis. Hourly measurements are necessary to align rainfall severity with flood complaint calls. It is important to note that storm patterns are not always uniform; for any given storm, the rainfall levels and storm severity often varies across region and during the duration of the storm**.** **Figure 6** , **Figure 7**, and **Figure 8** illustrate such storm patterns for a selection of storm dates.

Figure 6: Sample Minor Storms (Radar Precipitation and Storm Recurrence Interval Extent)

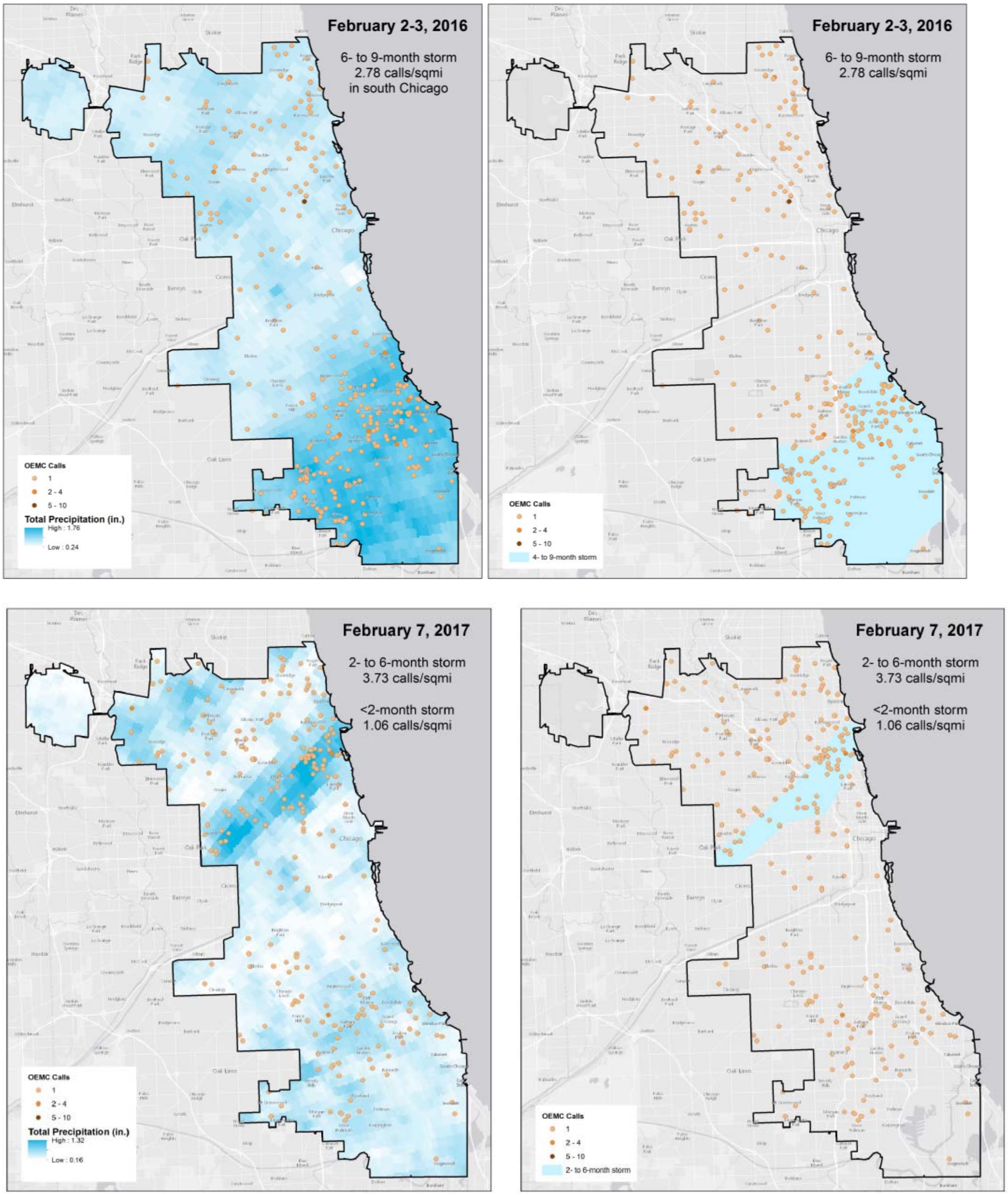


Figure 7: Sample Moderate Storms (Radar Precipitation and Storm Recurrence Interval Extent)

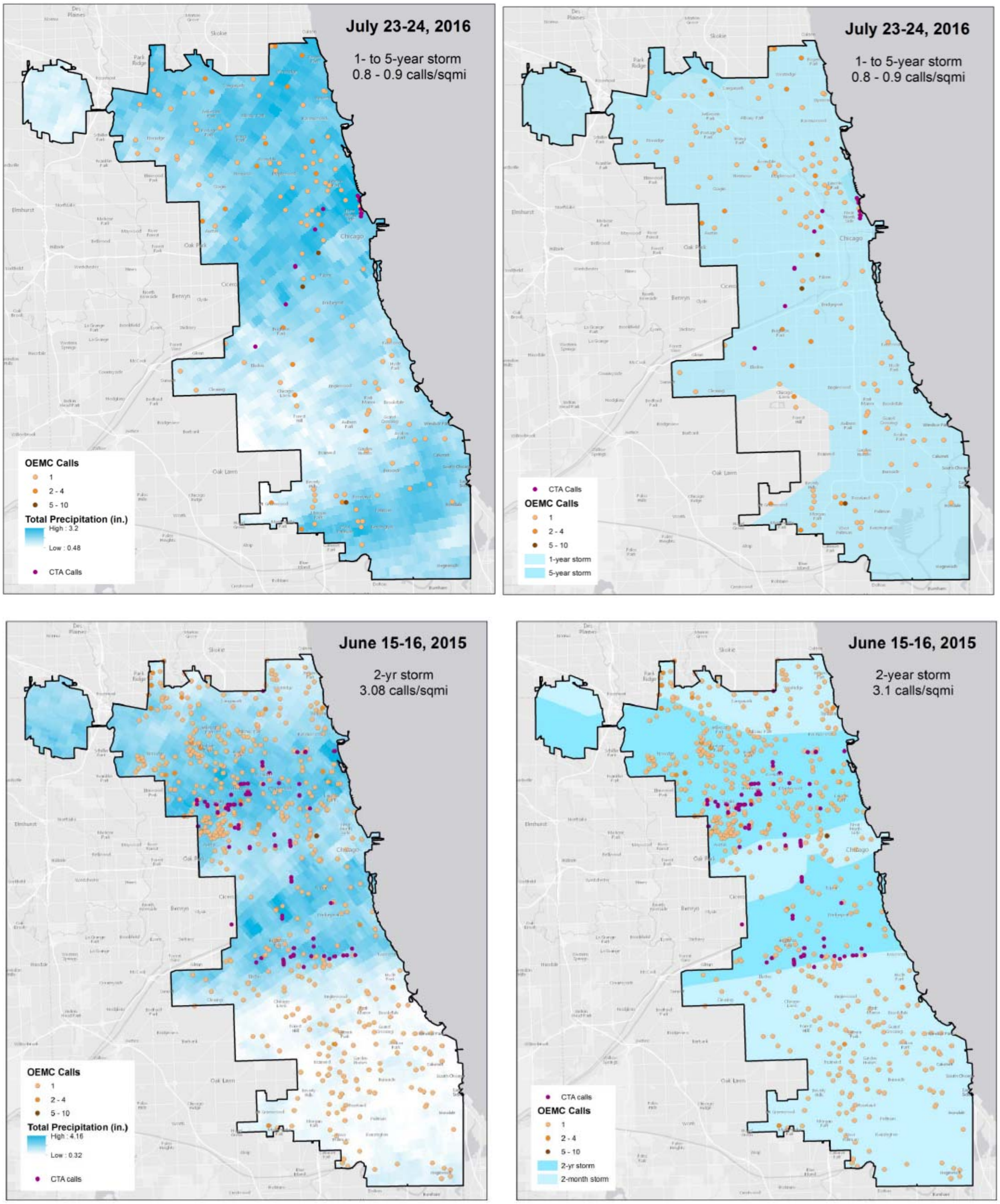
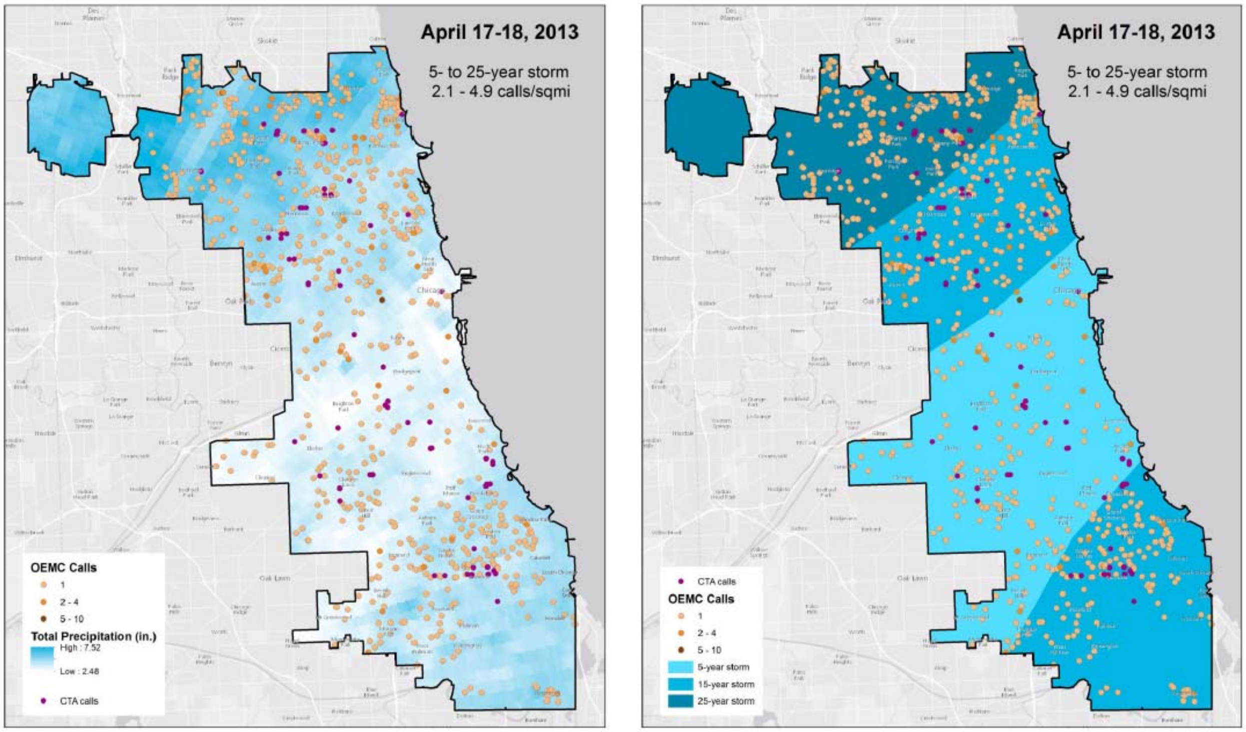


Figure 8: Sample Severe Storm (Radar Precipitation and Storm Recurrence Interval Extent)



CTA and OEMC flood complaint call data were correlated to the selected storms' rainfall data to identify spatial patterns and density of potentially recurring problems. It was noted that the density of OEMC 311 calls complaining about water on roadway and/or flooded viaducts increased with storm type, as shown in **Figure 9** and **Figure 10**. CTA drivers' reports of flood incidents generally found to correlate with moderate or more severe storms, that is, storms with 1-year recurrence intervals or greater.

This approach draws on a finite sample set of rainfall data *and* data documenting actual flood incidents reported by CTA staff or through OEMC via 311. While the available data is not particularly robust in terms of number of significant events and storm severity, the analysis provides valuable insight to areas of future risk for flooding that might impact CTA bus operations. The degree of severity of urban flooding can be subject to the human interventions by water departments to manage stormwater and sewer capacity across their networks and to discharge decisions at any given time. Therefore, this study cannot broadly draw spatial conclusions that areas currently prone to flooding will be larger or wider in the future – just that the intensity of flooding may be worse and/or more frequent. A more complex effort that models a greater base of rainfall, storm, and complaint data, together with dynamic sewer capacity management and/or hydraulic and hydrologic modeling may provide more precise conclusions but was beyond the schedule, scope and budget of this project.

Figure 9: OEMC 311 Calls in Minor to Major Storms

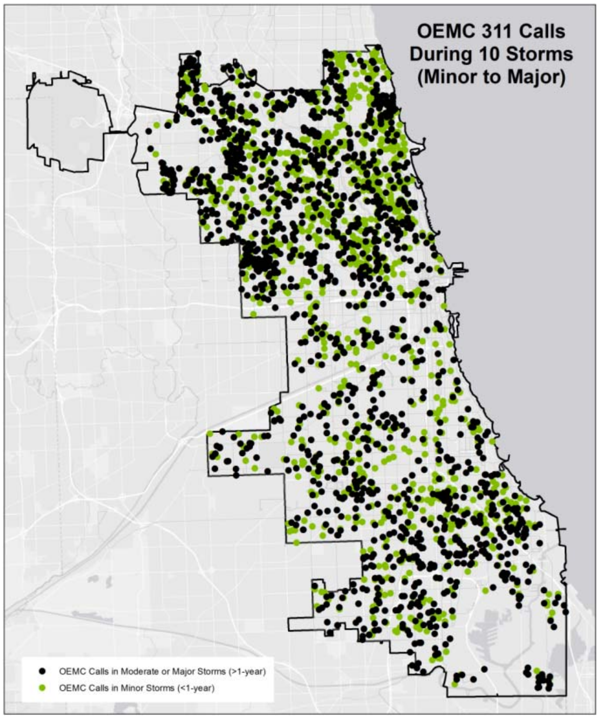
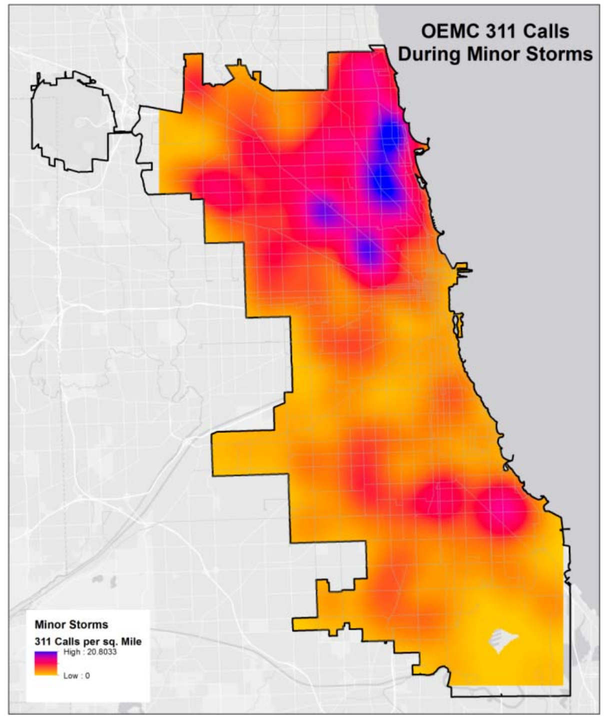


Figure 10: Density of Storms During Minor Storms (<1-Year Recurrence Interval)



2.2.2.3 Suburban/Exurban Flooding Methodology

The potential impact of future climate change over the next century on riverine and suburban/exurban flooding patterns and levels are available from a 2010 report by the US Army Corps of Engineers for several water bodies in the RTA service area. Water resource and stormwater specialists reviewed this information with a particular focus on the general areas through which Pace's Scenario E priority bus routes run. These include the Des Plaines River, Addison Creek, and Silver Creek. The storm profiles were reviewed to identify incremental surface elevation differences for various storm profiles. **Table 5** below presents these differences for the Des Plaines River.

Table 5: Des Plaines River Elevations

Flood Event Water Surface Profile	Elevation Increment (ft)
1- to 2-year	2
2- to 5-year	2
5- to 10-year	1
10- to 25-year	1
50- to 100-year	0.8
100- to 500-year	2.4

Source: USACE, August 2010

Based on these incremental differences and the storm frequency shift identified based on future rainfall amounts in Section 6.2.2.1, revised 100-year floodplain limits were drawn in GIS approximately half way between the existing FEMA 100- and 500-yr flood plain limits. In the absence of complex hydraulic and hydrologic modeling, this broad-brush approach is appropriate for identifying locations impacted by future conditions. This exercise concludes that there was very limited spatial expansion of floodplain areas impacting bus routes. This project's initial screening of Pace bus routes for risk of flood interruption was based on defining risk areas including both the 100 and 500 year floodplain limits, so adjustments for future conditions were already within the zones noted as potentially risk-prone. A sampling of the minor locations where the floodplain limits shifted are in **Figures 11** and **12** below, which appear to be very minor.

Across the RTA service region, there are few areas with 500 year floodplain concerns that intersect with bus routes. The conclusion from this exercise is similar to the conclusion for urban flooding: locations that are currently prone to flooding may have more frequent or severe flooding in the future. Due to the time and resource intensity of the processing required to model and truth-check these estimated boundaries, and the fact that a critical number of Pace routes impacted by flooding are in the Des Plaines River watershed, future 100-year floodplain limit adjustments were only made to that river system.

Figure 11: Pace Routes with Enhanced Flood Zones (Des Plaines)

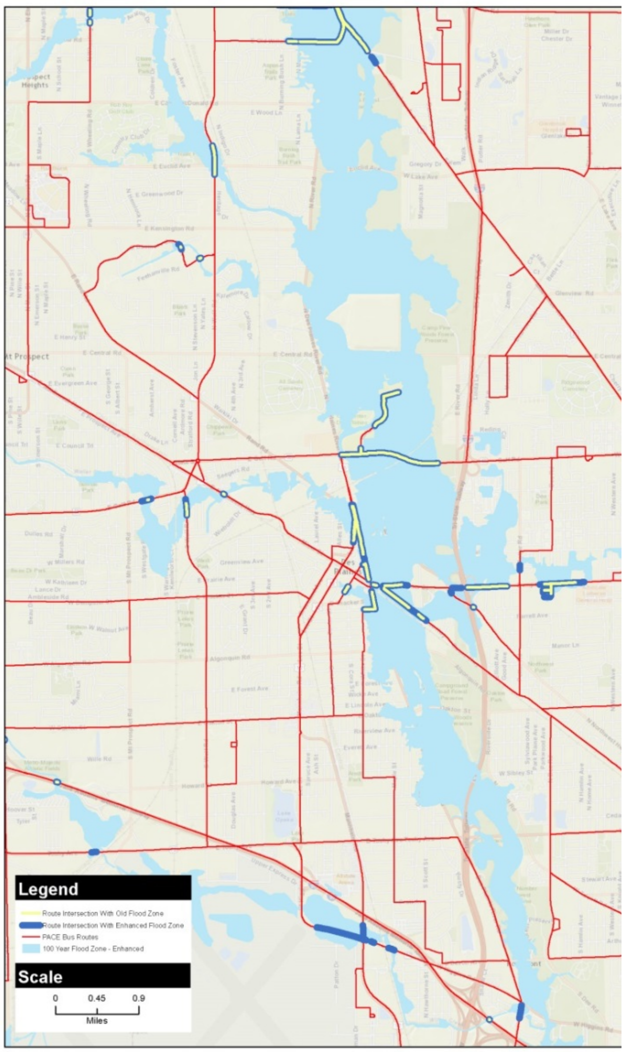
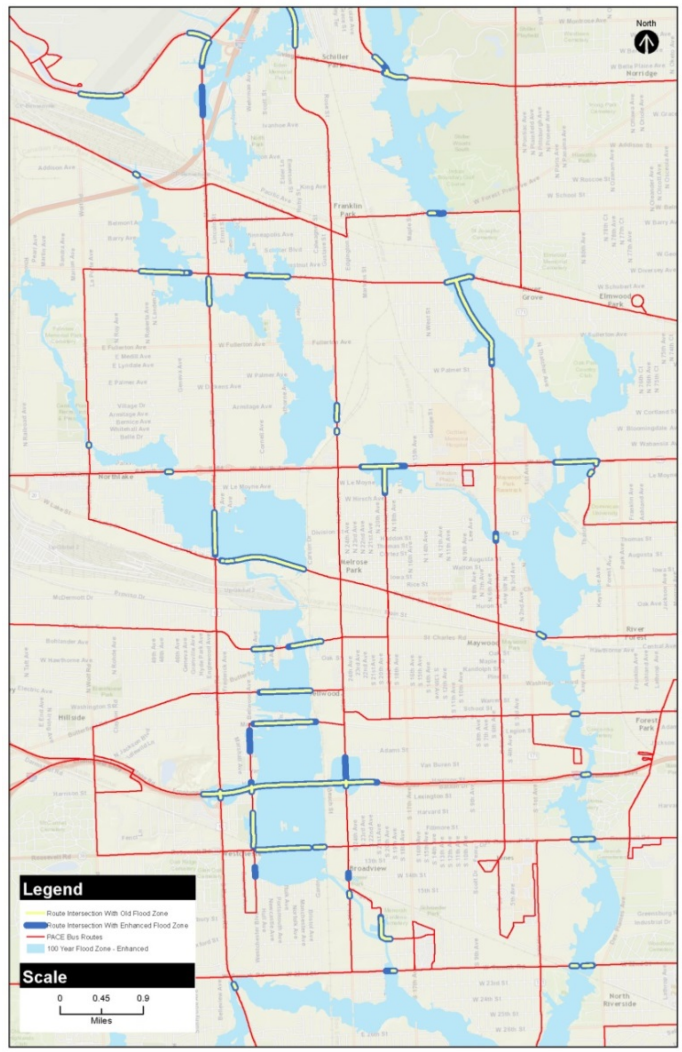


Figure 12: Pace Routes with Enhanced Flood Zones (Melrose Park)



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