A Revisit of Temporal and Spatial Variability and Resolution of Rainfall Measurements Relevant for Urban Hydrology
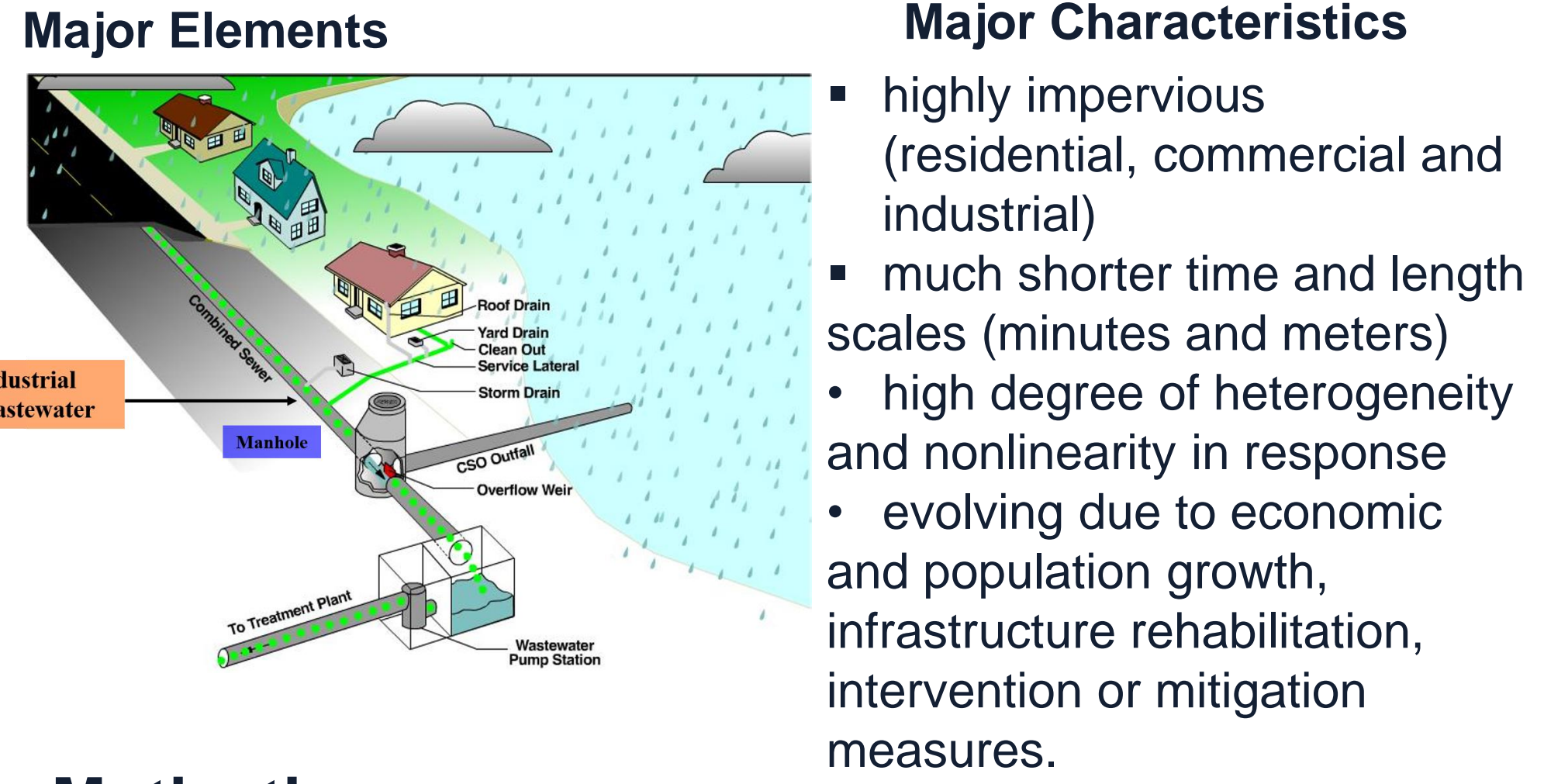
Hao Luo[1], Irene A. Crisologo[2], Daniel E. Horton[2], Scott M. Collis[3], Aaron Packman[2], Marcelo H. Garcia[1]

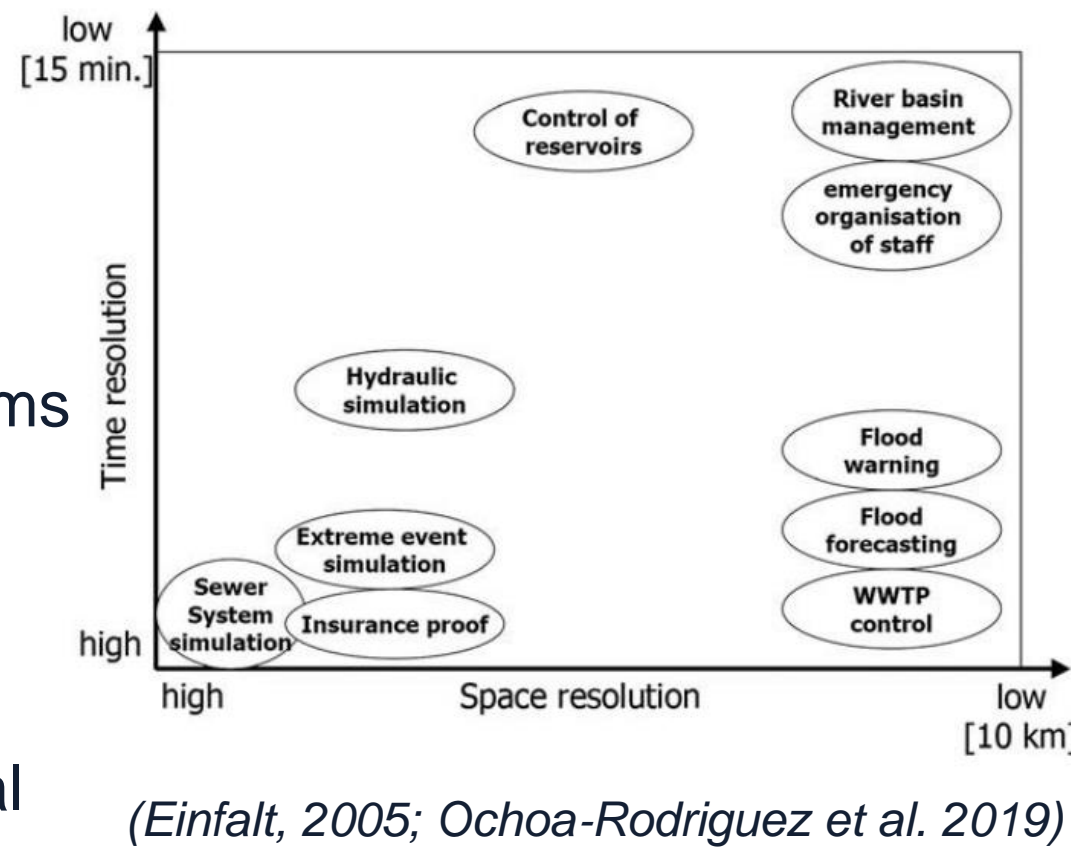[1]University of Illinois at Urbana-Champaign; [2]Northwestern University; [3]Argonne National Laboratory

INTRODUCTION

➤ Urban drainage system

Major Elements

Major Characteristics

- highly impervious (residential, commercial and industrial)
- much shorter time and length scales (minutes and meters)
- high degree of heterogeneity and nonlinearity in response
- evolving due to economic and population growth, infrastructure rehabilitation, intervention or mitigation measures.
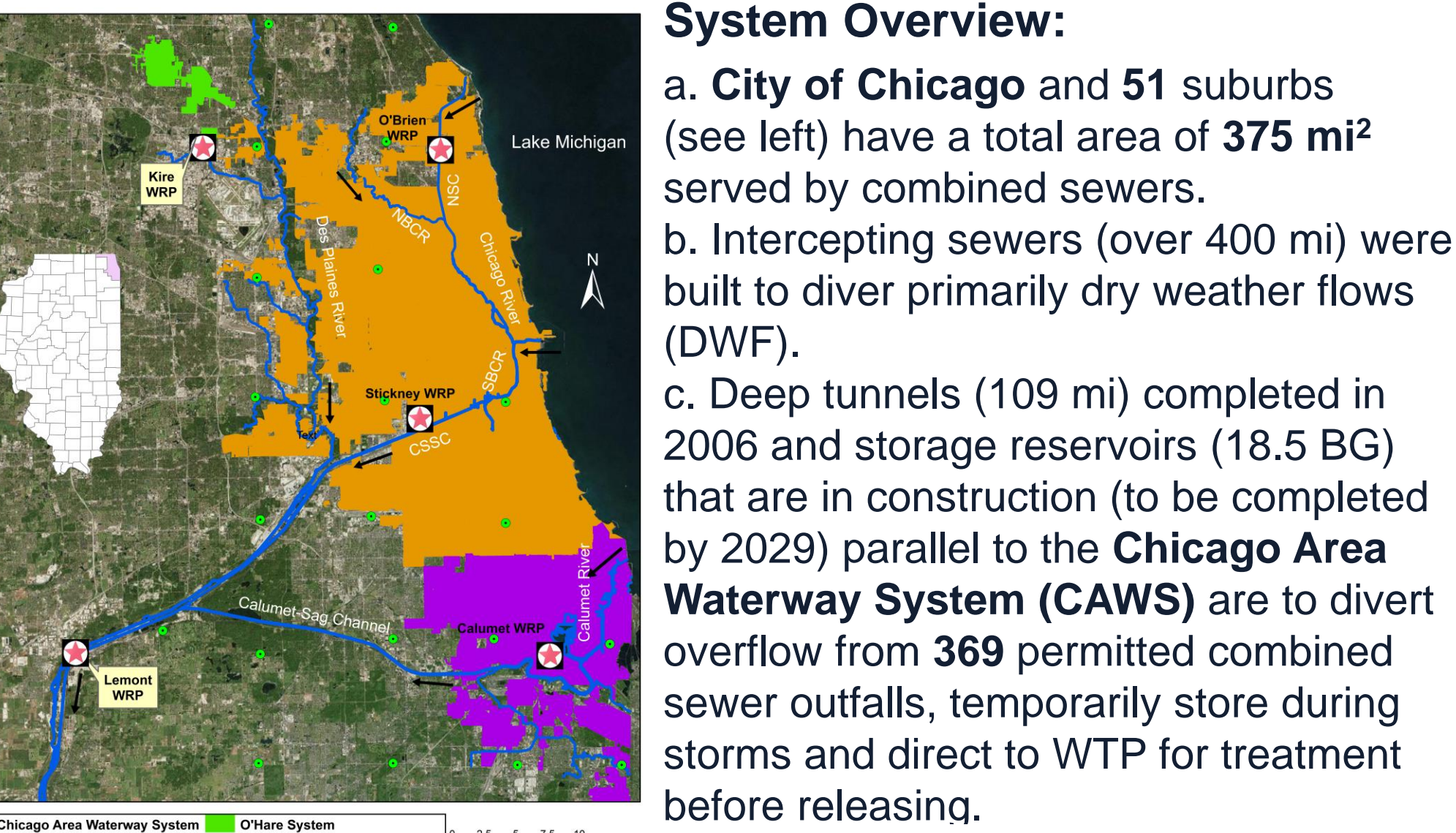
➤ Motivations

- Rainfall is the driving mechanism of urban runoff.
- Localized and severe flash storms can cause citywide flooding, leading drainage systems to surcharge and overflow to nearby water courses.
- The observed tempo-spatial variability of rainfall has a significant impact on hydrological systems and constitutes a major source of uncertainty for urban hydrologic modeling.
- The small space-time scales of urban catchments and complex underground drainage systems require rainfall data at the fine spatial-temporal resolutions.

(Einfalt, 2005; Ochoa-Rodriguez et al. 2019)

- The developments in GIS and detailed urban drainage models, emerging data resources and computational power facilitated the integration of radar rainfall estimates in urban hydrology.

Background and Materials

➤ Greater Chicago Urban Drainage System

System Overview:

a. **City of Chicago** and 51 suburbs (see left) have a total area of **375 mi²** served by combined sewers.
b. Intercepting sewers (over 400 mi) were built to diver primarily dry weather flows (DWF).
c. Deep tunnels (109 mi) completed in 2006 and storage reservoirs (18.5 BG) that are in construction (to be completed by 2029) parallel to the **Chicago Area Waterway System (CAWS)** are to divert overflow from **369** permitted combined sewer outfalls, temporarily store during storms and direct to WTP for treatment before releasing.
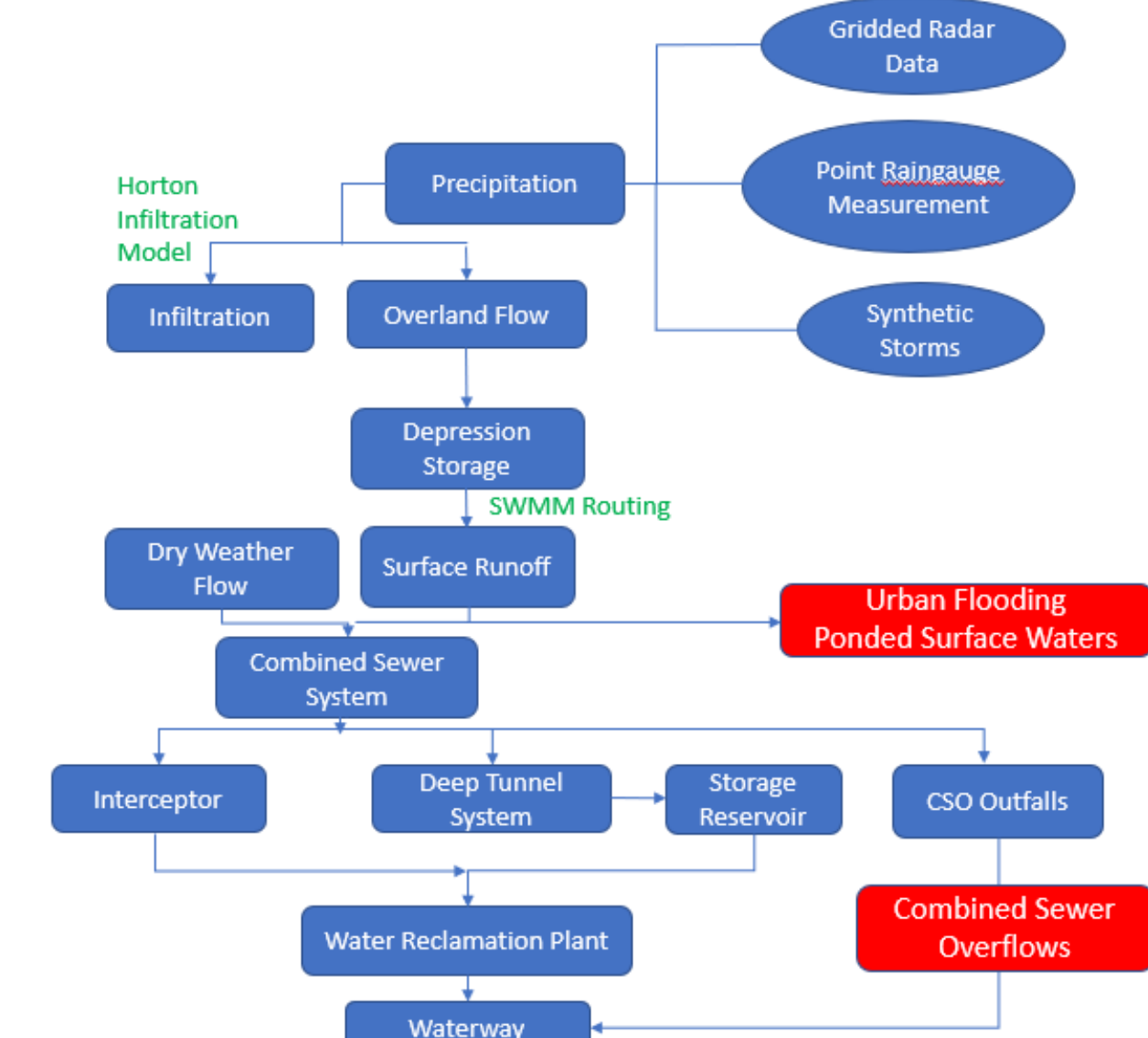
➤ Study Area

a. Based on a simplified representation of the entire sewer system in City of Chicago (>24 in).

b. The watershed has been divided to nine model areas which were further delineated into 6594 subcatchments (see right) with median size of 4.7×10^4 m².
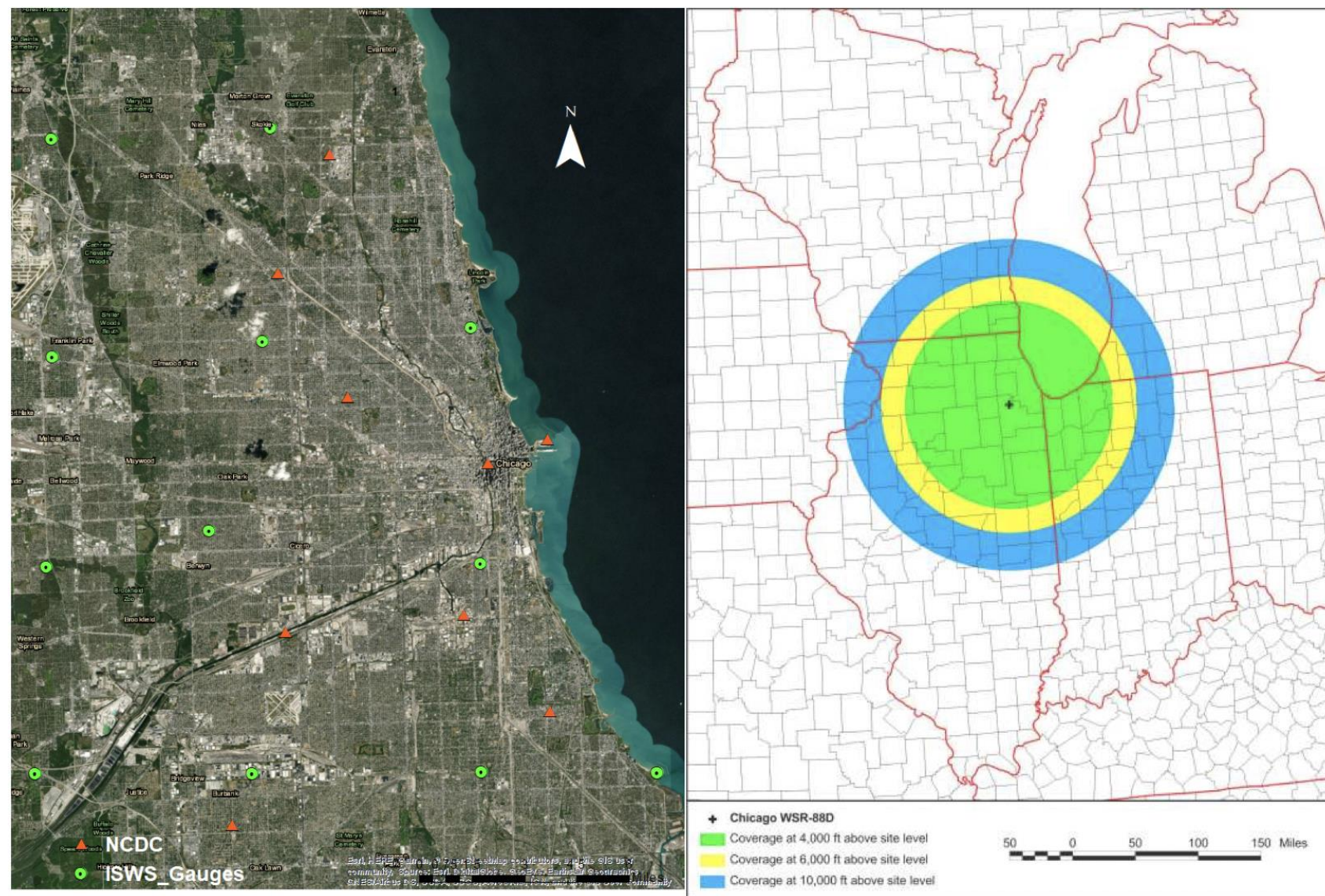
c. Areal-averaged imperviousness is 63%.

METHOD

➤ Integrated Hydrologic and Hydraulic Model

Simplified Modelized Flow Chart

- 1-D detailed numerical model originally developed for entire drainage system across City of Chicago (for the Department of Water Management) using the InfoWorks CS package is employed to integrate rainfall derived from raingauge network and radar

- Solves the 1-D Saint-Venant Equations in conjunction with Preissmann slot for pressurized flow simulating the complex flow in the highly looped city sewer network.

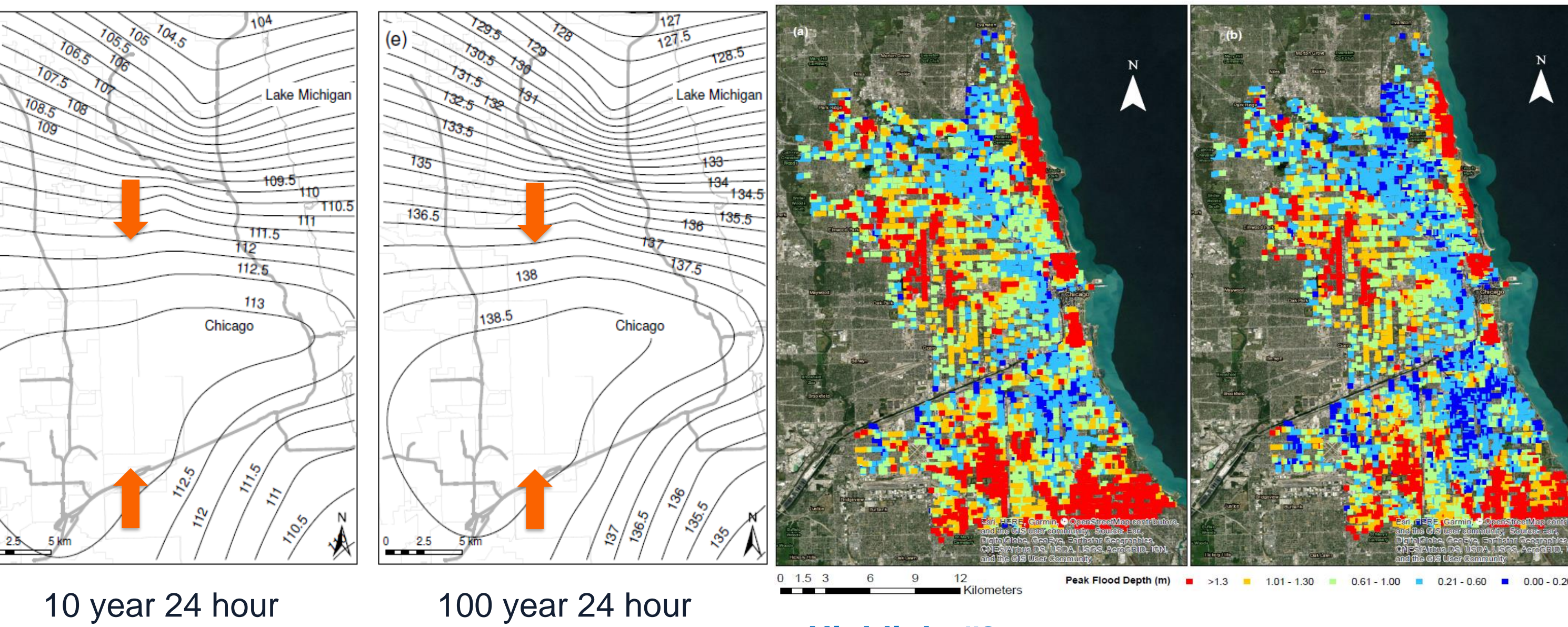### ➤ Description of Rainfall Data

a. **Rain gauge:** Illinois State Water Survey (ISWS) operated, 9 out of a 25-membered hourly rain gauge network spaced ~10 km apart.

b. **National Climate Data Center (NCDC) Stations:** distributed **precipitation frequency (PF)** analysis are used to generate synthetic storms.

c. **NEXRAD Radar Level III Data:** a single WSR-88D dual-polarimetric weather radar with precipitation resolved every 5 minutes at 500 m and 1km, a Z-R relationship is deployed to generate quantitative precipitation estimation (QEP) at each grid.

Rain gauge and NCDC weather stations (left); NEXRAD radar coverage for KLOT, Chicago, IL., (right) courtesy http://www.ncdc.noaa.gov/oa/ncdc.html

Results & Discussions

➤ **Synthetic storms:** 100-year ARI design storms with **6 hour** durations based on NCDC PF data (rainfall depth) and Huff distribution (temporal).
➤ **Historical storms :** rainfall data from the **ISWS** and **NEXRAD radar** for storms on **April 17-18, 2013 (25-year recurrence interval).**
❖ **Storage conditions:** For synthetic storms, two storage conditions w/o storage from deep tunnel system; For historical storms, no storage from deep tunnel system were included.

• Maps showing regional rainfall frequency and spatial variation 24 hour storm (plotting rainfall depth in mm)

10 year 24 hour   100 year 24 hour

• Maps showing flooding risks from 100 Year 6 hour ARI storms with historical (left) and projected storage (right)
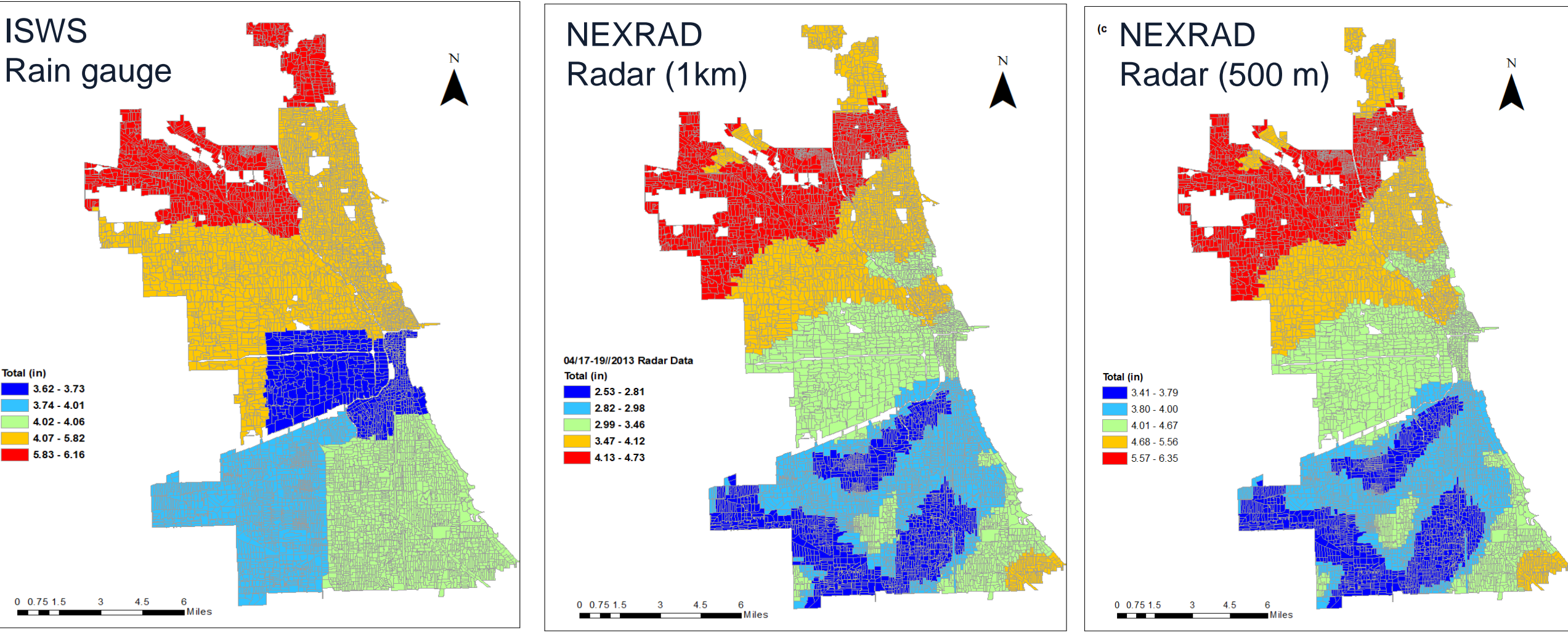

Highlight #1

a. Intense storms of the same duration follow the same spatial pattern. More rain are likely to fall in middle system, i.e. Chicago metropolitan area.

b. Greater spatial gradient is observed for more intense storms.

Highlight #2

a. Less flooding risks predicted in the areas near CAWS, areas along Northshore and southern suburbs are more prone to flooding.

b. With additional storage provided by tunnel and reservoir system, the flooding risks is reduced extensively from inland to near shore areas.
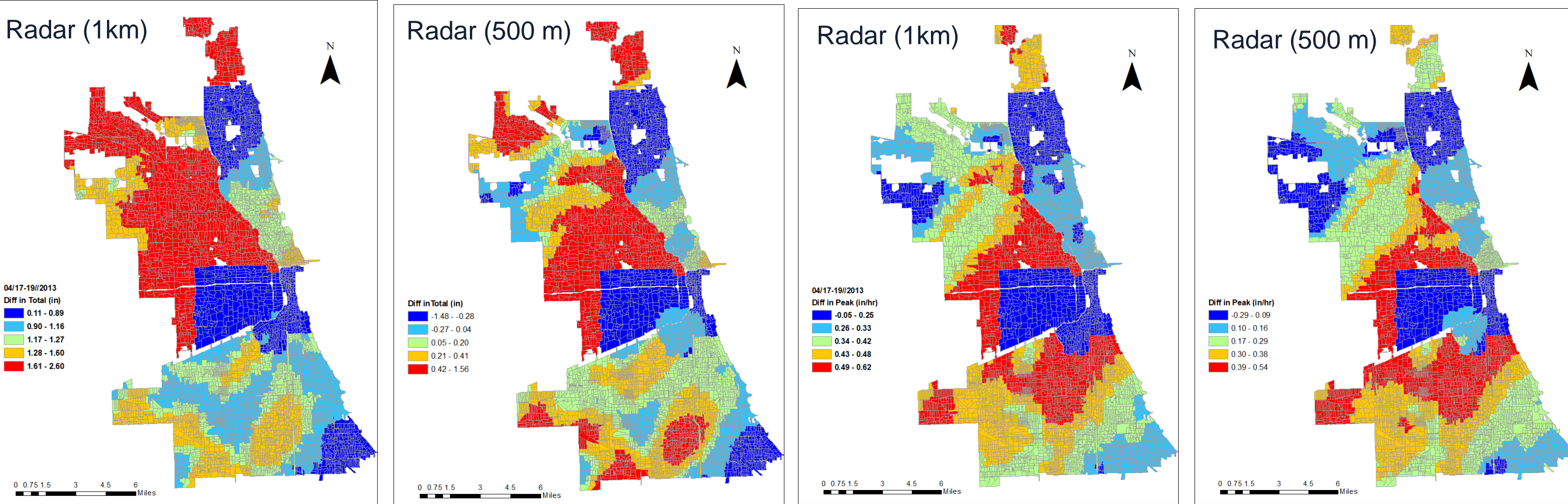
Results

• Maps showing comparison between Radar derived and Rain gauge data based on quantile classification for a severe storm event on April 17-18, 2013

Highlight #3

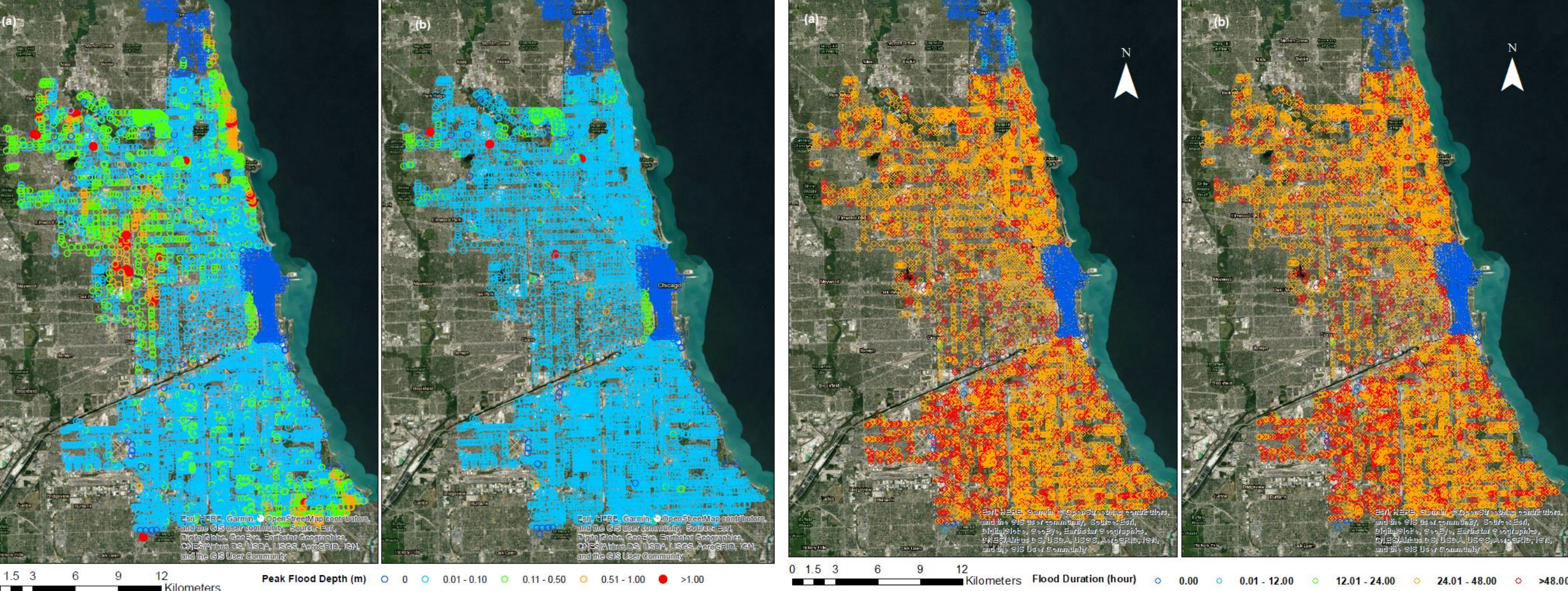ISWS Rain gauge   NEXRAD Radar (1km)   NEXRAD Radar (500 m)

a. The rainfall follows the alike spatial pattern for two radar data sets resolved at 500 m and 1km; however, the magnitudes differs with the former about 40% greater than the latter.
b. The radar data in finer resolution resembles the rain gauge data quantitatively better.

• Maps showing Residuals between Rain gauge measurements and Radar QEPs in terms of totals and peak.

Radar (1km)   Radar (500 m)   Radar (1km)   Radar (500 m)

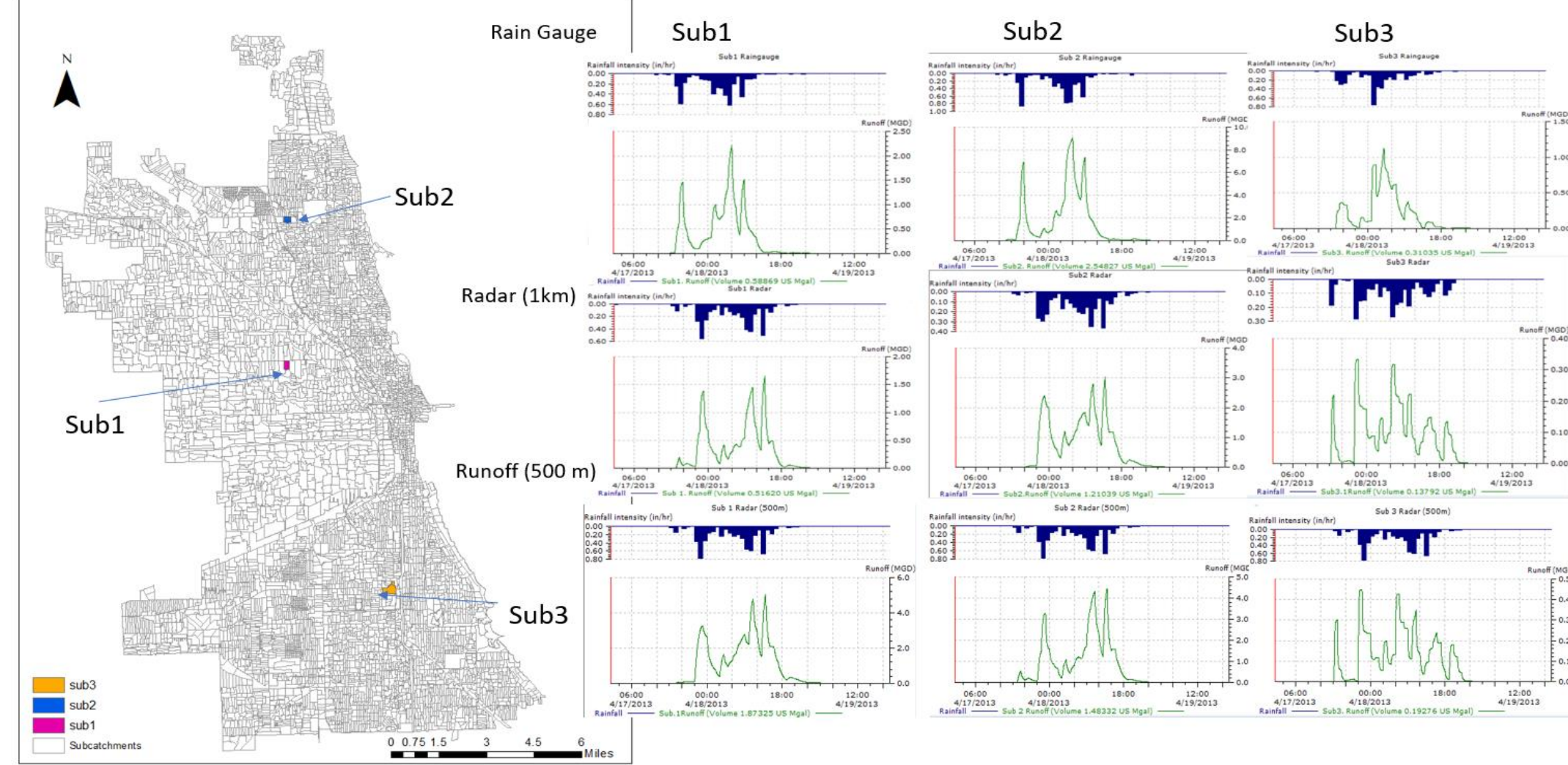### ➤ Impact on simulated hydrologic response

• Maps showing City Street Flooding Risks predicted using rain gauge and radar (1km)

Highlight #4

a. The differences in rainfall input result in dramatic differences in the simulated floods in terms of peaks and spread.

• Maps showing surface runoff predicted using rain gauge and radar (1km)

b. At different geographical location the rainfall derived from different approaches and at various resolution differ in their spatial and temporal pattern due to inherent differences between direct and indirect measurements, which further result in obvious differences in predicted surface runoff, the volume, peak and hydrograph passages. Regardless, the two sets of radar data resemble in temporal structure, however, differs in magnitudes.