



Metropolitan Water Reclamation District of Greater Chicago

**Welcome to the October
Edition of the 2023 M&R
Seminar Series**

NOTES FOR SEMINAR ATTENDEES

- Remote attendees' audio lines have been muted to minimize background noise. **For attendees in the auditorium, please silence your phones.**
- A question and answer session will follow the presentation.
- For remote attendees, Please use the “**Chat**” feature to ask a question via text to “**Host.**” **For attendees in the auditorium, please raise your hand and wait for the microphone to ask a verbal question.**
- The presentation slides will be posted on the MWRD website after the seminar.
- This seminar is pending approval the ISPE for one PDH and has been approved by the IEPA for one TCH. Certificates will only be issued to participants who attend the entire presentation.

Abhinav Wadhwa, Ph.D.

**Postdoctoral Scholar, Discovery Partner Institute
University of Illinois, Champaign, Illinois**



Dr. Wadhwa, who holds a PhD in Water Resource Engineering, is currently engaged in the development of flood forecasting systems and sustainable flood mitigation solutions. He is a postdoctoral scholar at Discovery Partner Institute, University of Illinois Systems. His research interest lies in Water Resource Engineering, Urban Stormwater Management, Uncertainty and Fuzzy system, Life Cycle Assessment, Sustainability, Remote Sensing and GIS, Urban Planning and Management, Analytic Hierarchy Processing, and Climate Change Adaptation. His work involves the integration of 1D-2D hydrological models with NWP model forecasts. He is currently involved in developing a Climate Assessment Report for the QUAD cities in collaboration with the National Wildlife Federation. The major theme of the assessment revolves around developing the hydrodynamic model to provide flood inundation scenarios for climate models and sustainable solutions to prevent flooding in the QUAD cities.



DISCOVERY PARTNERS INSTITUTE
PART OF THE UNIVERSITY OF ILLINOIS SYSTEM

26th October 2023

Abhinav Wadhwa
Postdoctoral Researcher

Tech

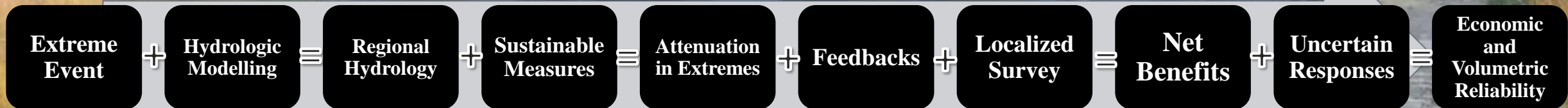
Talent

Research

Near to Real-Time Flood Forecasting: Towards Digital Twins at Urban Scales

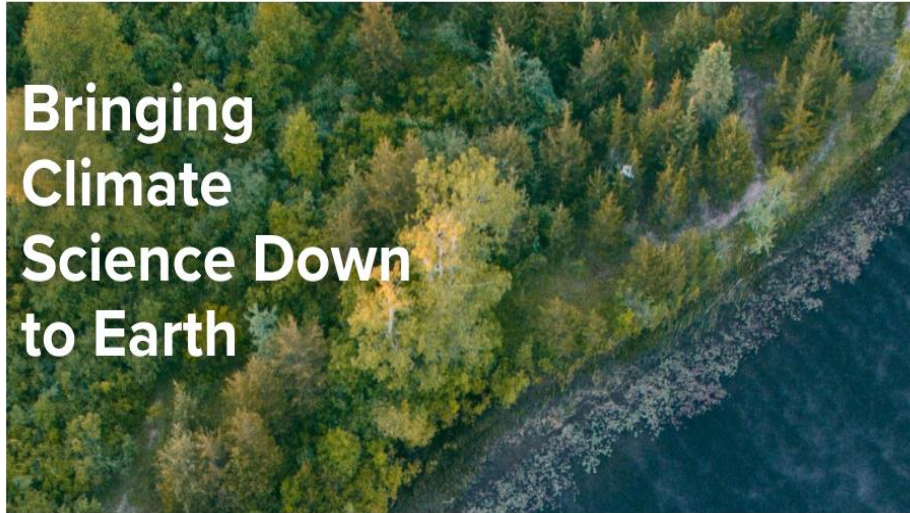
Key Contents

- **Climate Ecosystem at DPI**
- **Introduction to Digital Twin**
 - **Digital Twin in Hydrology**
- **AI/ML Approach**
 - **Data Maturity**
 - **Temporal Downscaling**
- **Decentralized/Combined Sewer System**
- **Nature-based Solutions to Mitigate Extremes**
 - **NbS in Carbon Neutrality**
 - **NbS in Runoff Reduction**
 - **Sustainable Flood Risk Management**
- **Vision for Urban Cities**
 - **Future Scope**
 - **Early Warning System/Dashboard**





Climate Ecosystem at DPI



Bringing Climate Science Down to Earth



Working with federal agencies, industry and academic partners to build a climate intelligence ecosystem that translates state-of-the-art climate science to provide focused solutions and services and update critical policies to guide climate-resilient decisions

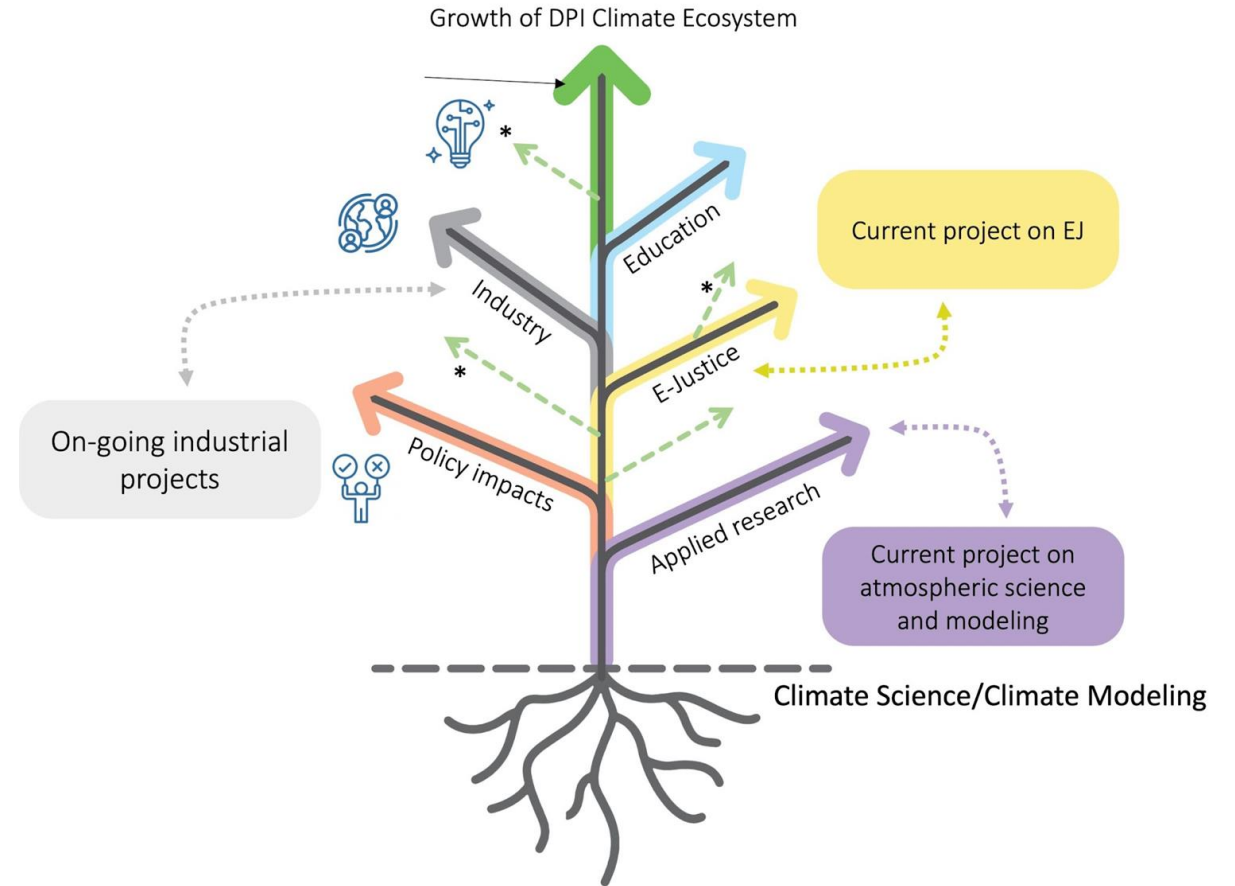
What we do

- Basic and applied research
- Climate consulting practice
- Empower climate-resilient communities
- Environmental policy



<https://www.climate-dpi.org/>

DPI Climate Ecosystem Tree



Our climate intelligence ecosystem translates state-of-the-art climate science to provide focused solutions and services and update critical policies to guide climate-resilient decisions.

Climate Assessments

ENVIRONMENTAL LAW & POLICY CENTER

An Assessment of the Impacts of Climate Change on the Great Lakes

by Scientists and Experts from Universities and Institutions in the Great Lakes Region

U.S. Congress June 9, 2019

AN ASSESSMENT OF THE IMPACTS OF CLIMATE CHANGE IN ILLINOIS

The Nature Conservancy

CLIMATE ACTION PLAN FOR THE CHICAGO REGION 2021

Metropolitan Mayors Caucus

CPD CLIMATE PROGRAM OFFICE | helping people, businesses, and the environment thrive in a changing climate

Earth System Science and Modeling Division: Extreme Heat Workshop

As "the Blob" took shape

SEPTEMBER 2014

Climate Research to Enhance Resilience to Extreme Heat
Aligning research priorities with stakeholder needs
November 2019, Silver Spring, MD

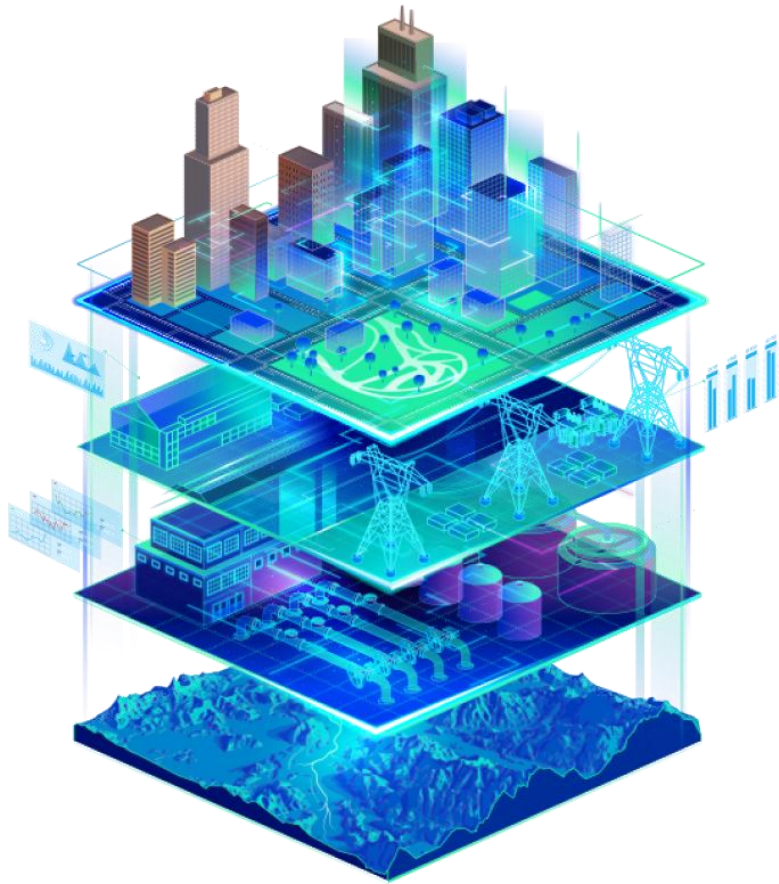
Workshop Organizers* and Session Chairs

Jin Huang (NOAA/OAR/CPO)*	Ashish Sharma (U Illinois)	Yi Ming (OAR/GFDL)
Annamaria Mariotti (OAR/CPO)*	Danica Lombardozi (NCAR)	Patrick Lynch (NOAA/NMFS)
Virginia Setz (OAR/CPO)*	Rong Fu (UCLA)	Edmund Chang (Stony Brook)
Ana Barros (Duke)*	Vaishali Naik (OAR/GFDL)	Juli Ttranj (OAR/CPO)
Tom Delworth (OAR/GFDL)*	Russell Vose (NOAA/NCEI)	Gregory Frost (OAR/CSL)
Jim Hurrell (CSU)*		
Eric Williams (OAR/CSL)*		

VISIT [CPO.NOAA.GOV/ESSM](https://cpo.noaa.gov/essm) EMAIL: OAR.CPO.ESSM@NOAA.GOV

Introduction to Digital Twin

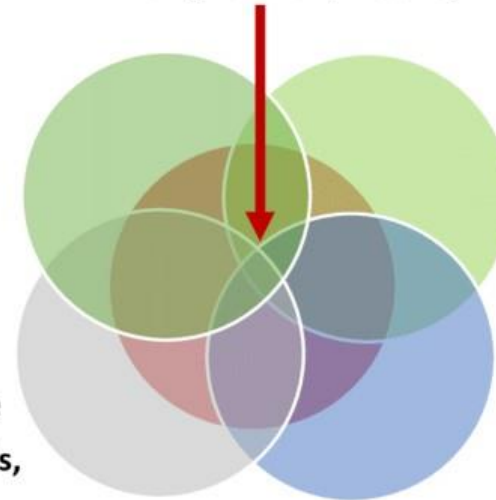
Digital Twin



Essential service provision
 e.g., energy, communications,
 health, finance, transport, food &
 water provision, security

Human infrastructure
 E.g., economic, cultural, social networks & structures

Grey infrastructure
 E.g., buildings, roads, bridges, drains

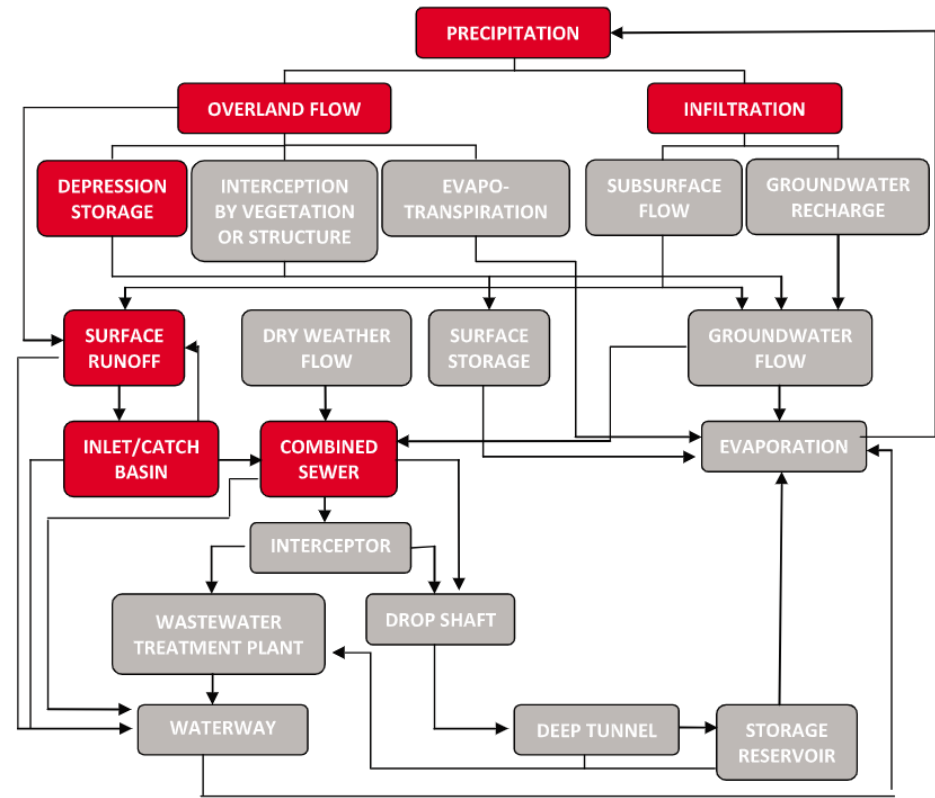


Green infrastructure
 E.g., urban forests, parks, trees, living walls, green roofs, sport fields, agriculture

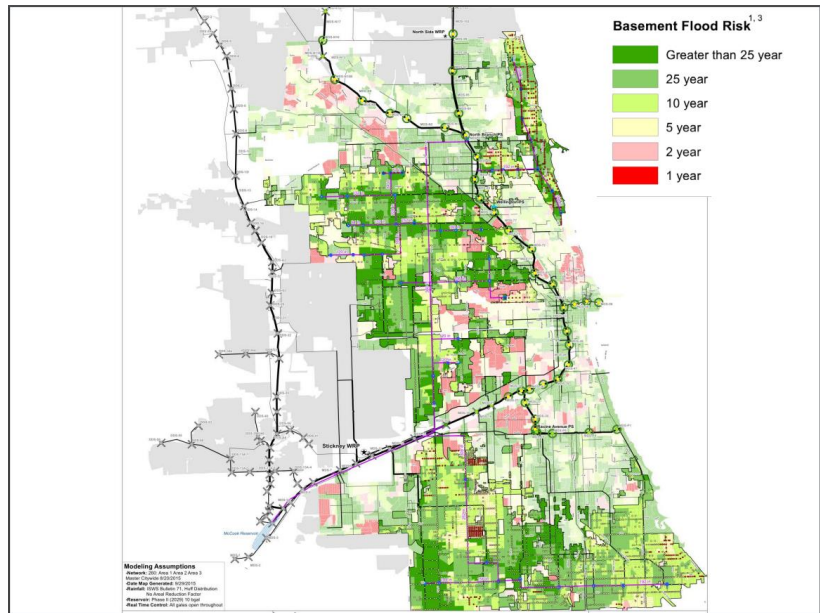
Blue infrastructure
 E.g., water-sensitive urban design, waterways

A digital twin is a virtual representation of a city, which can be used for the conception, the testing, the surveillance, the optimization, and the maintenance.

Towards Digital Twin

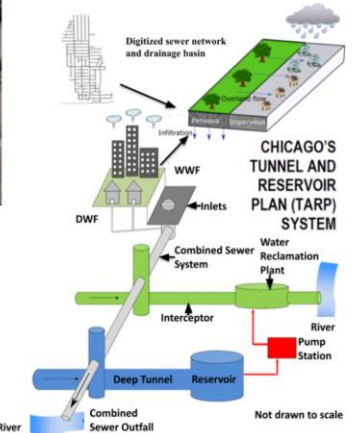


Joshua and Arthur, 2011



Source: MWRD

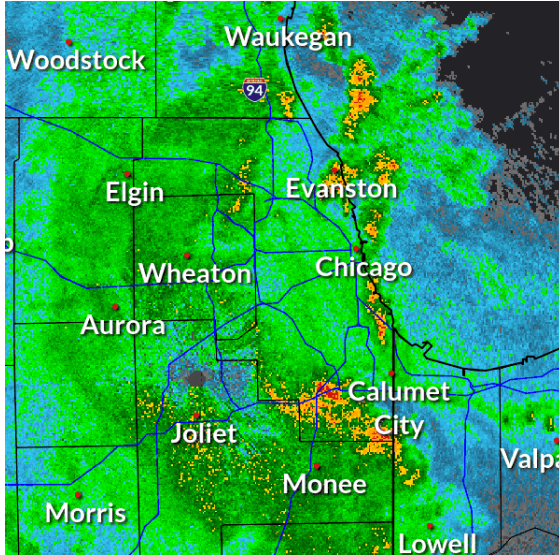
Tunnel and Reservoir Plan (TARP)



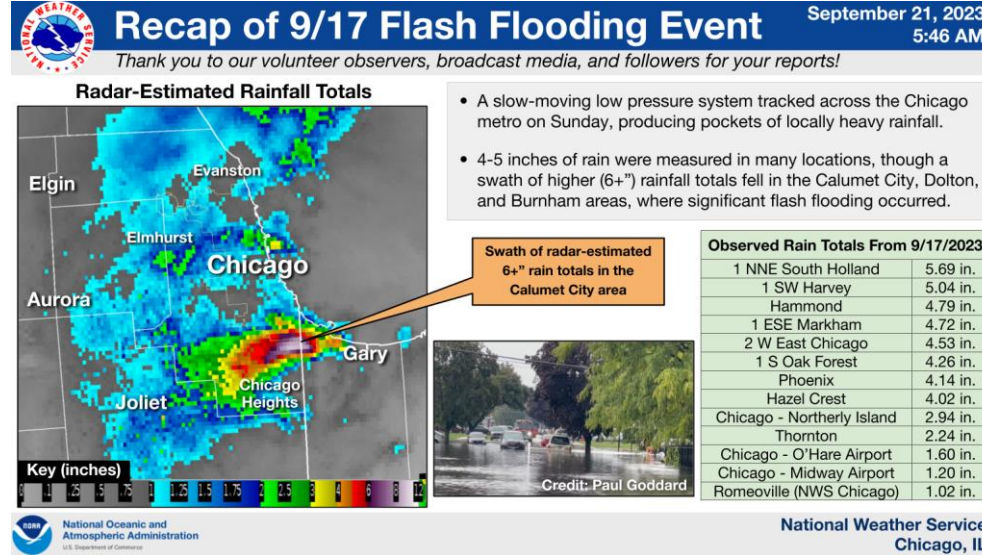
Source: MWRD

Digital Twin Benefits

Flash Flooding Suburbs of Chicago



NWS Radar Map

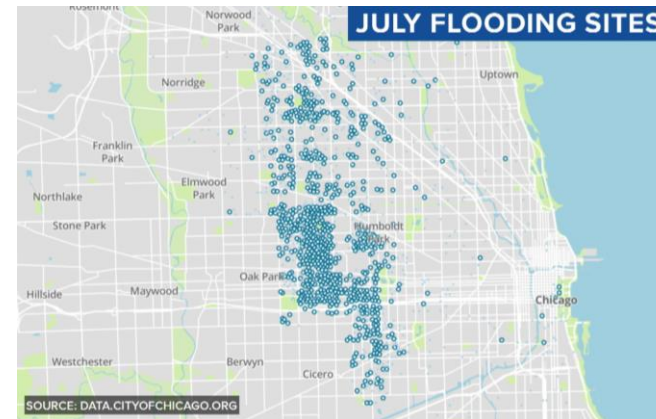


Flood forecast by NWS



Will street/building scale help?

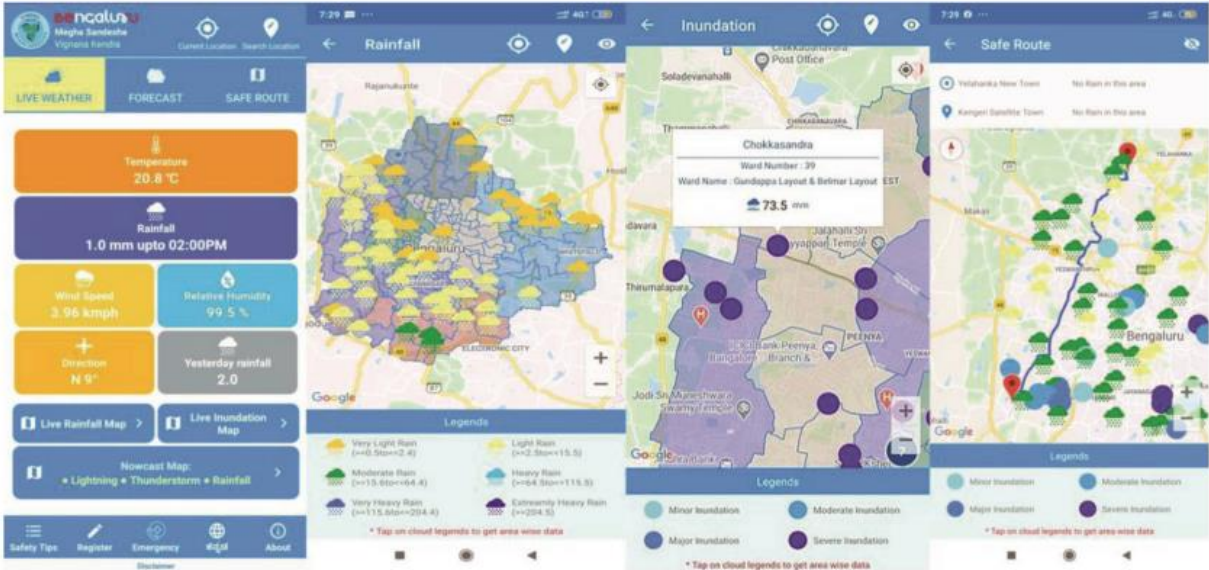
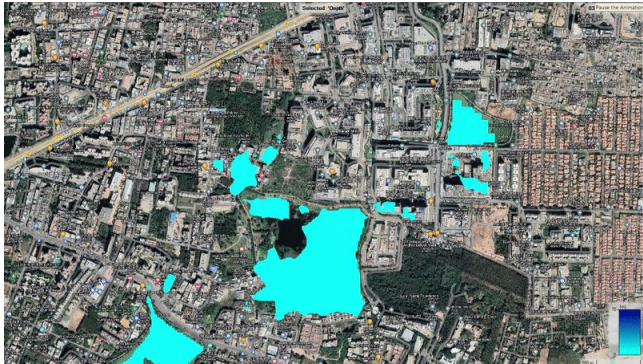
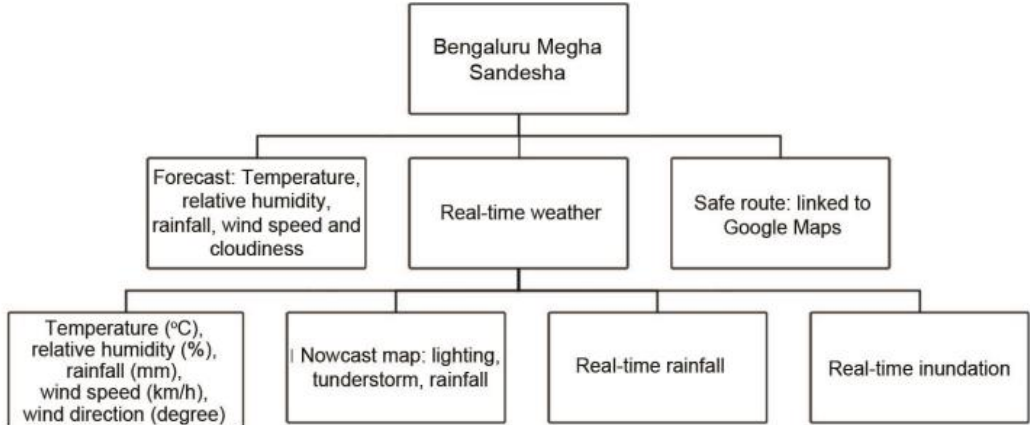
Research hypothesis structure: stakeholders and ground level engineers experience



Post event relief

Towards Digital Twins – An Example from an urban city in India

Towards Digital Twins



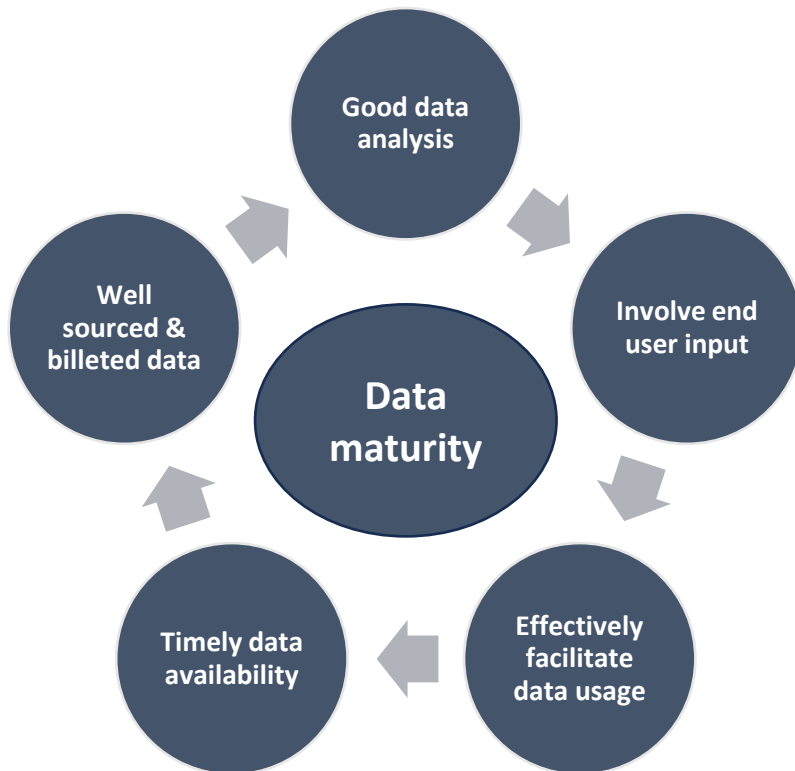


Key element for implementing digital twins is data maturity

Data maturity using AI/ML approach

Data Maturity

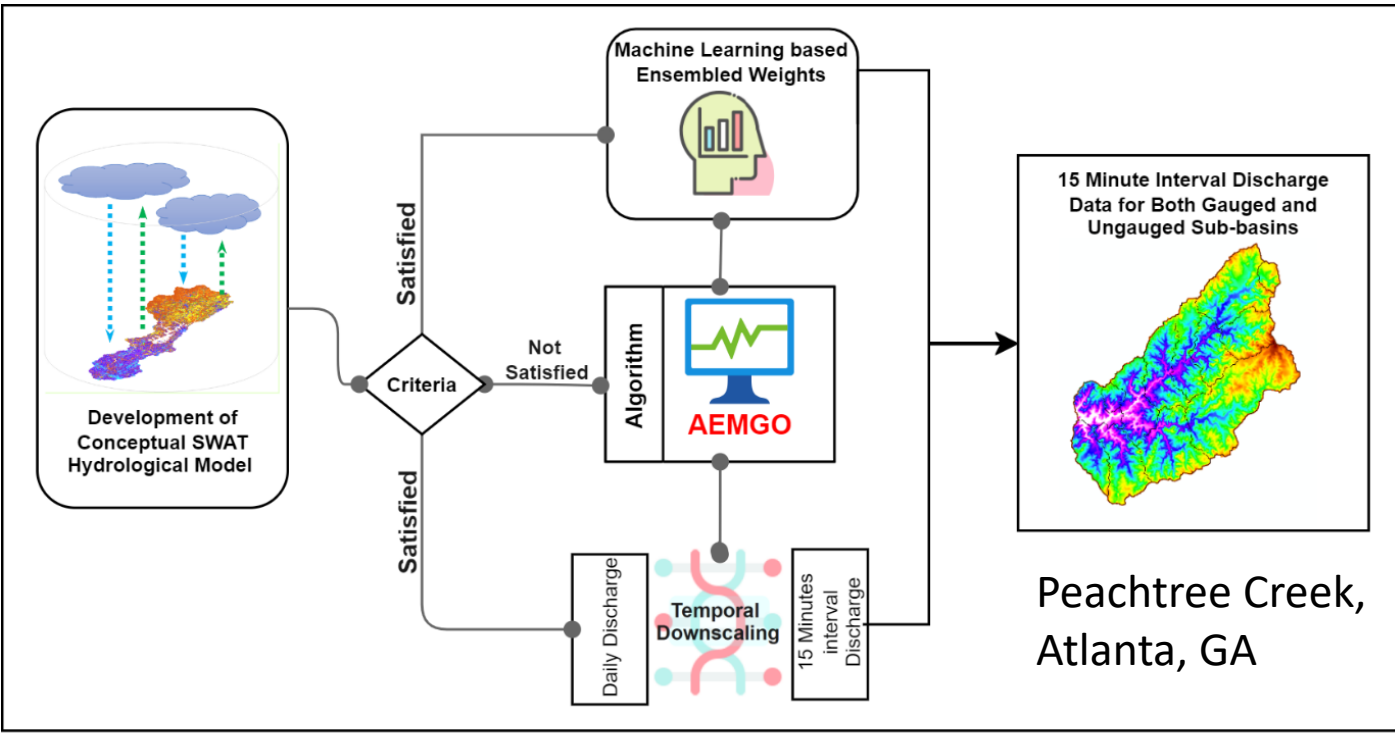
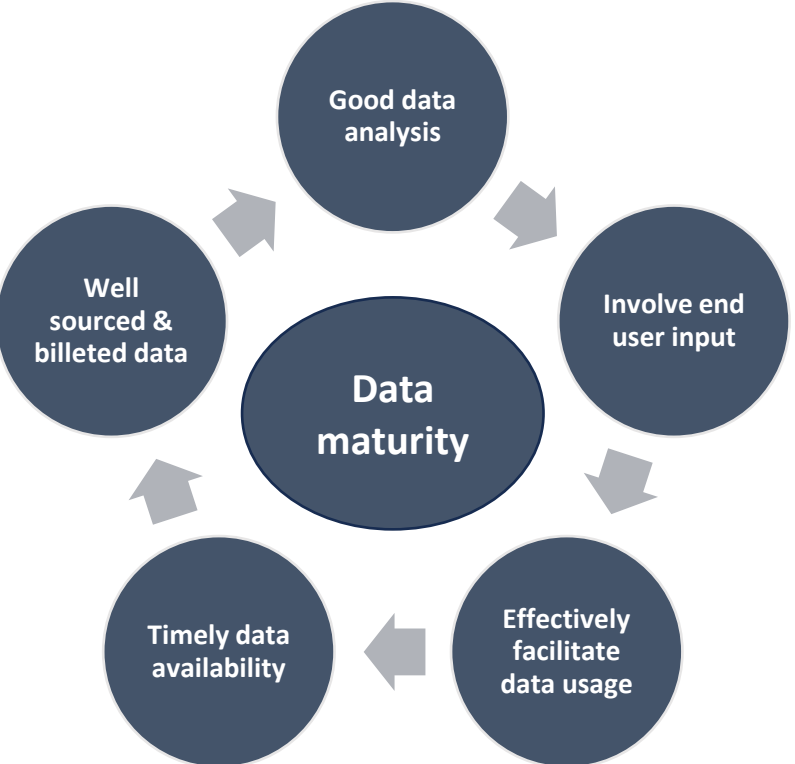
- Uncalibrated models with matured datasets → better performance
- Data maturity – advantage



**Feeble Data
Maturity?**

Data Maturity

- Uncalibrated models with matured datasets → better performance
- Data maturity – advantage



SWAT: Soil Water Assessment Tool
 AEMGO: Adaptive Emulator Modelling-based Genetic Optimization



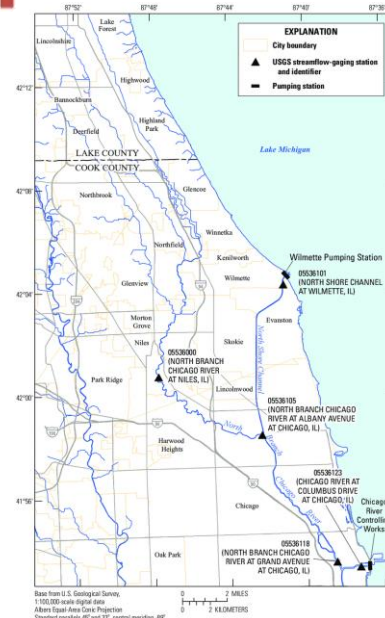
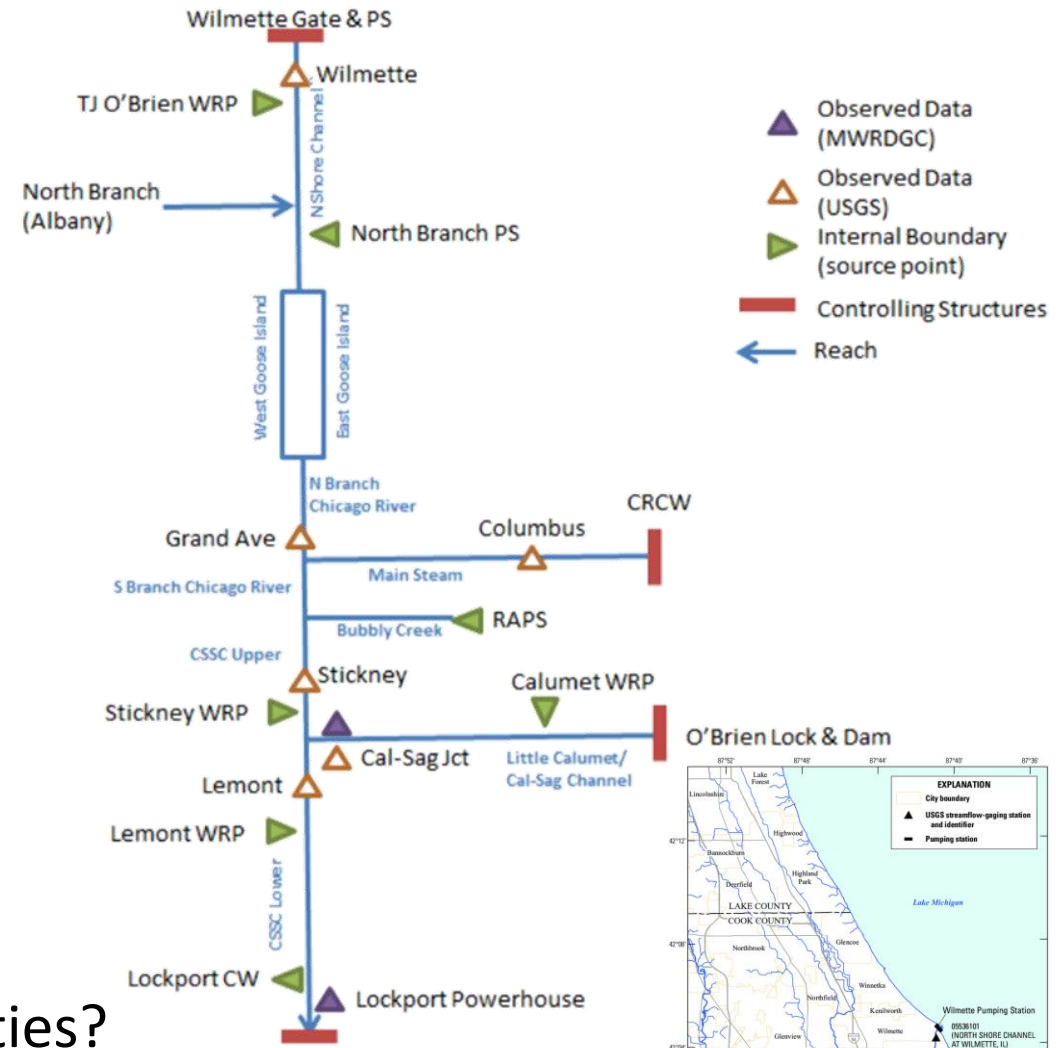
Data Complexities

Chicago Area Waterway System (CAWS) issues and complexities

- Lake Michigan diversion accounting
- Long-term regional water supply
- Invasive species
- Waterway separation
- Regional waterway transportation
- Local and regional flood control issues.

Questions we are interested in:

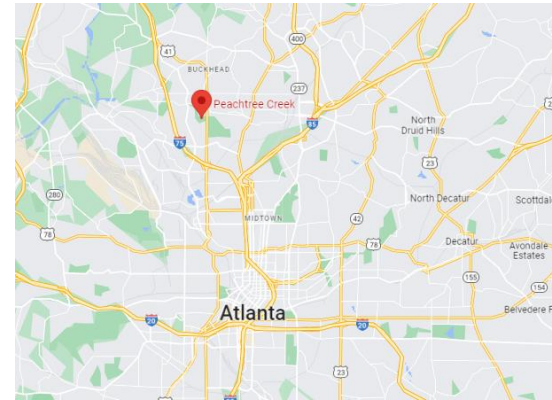
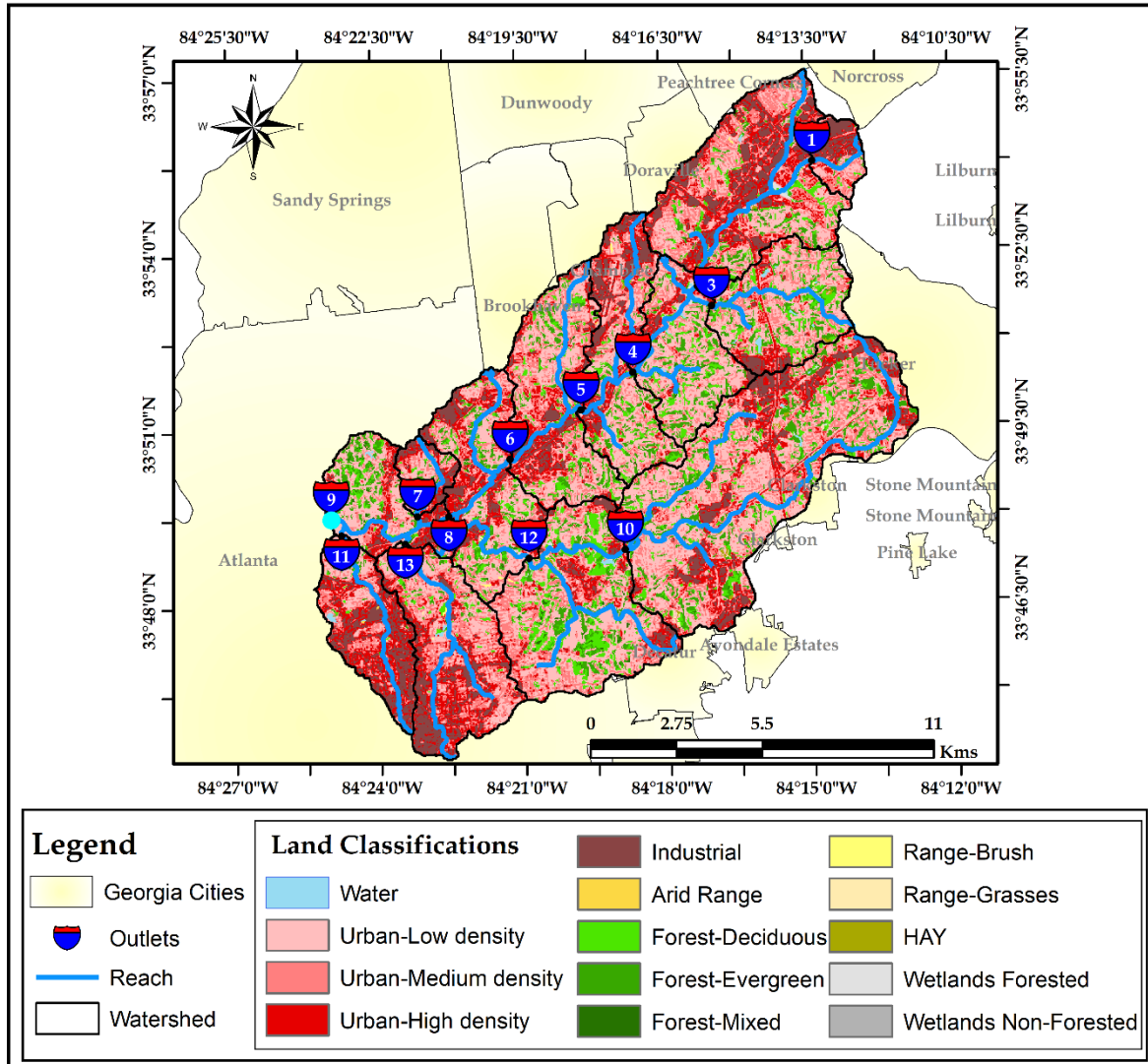
- How can we fill in the missing gaps in complexities?
- How near real-time station outputs can be useful?



An example of Peachtree Creek, Atlanta, GA....

Highlight: Obtain fine resolution data at ungauged stations

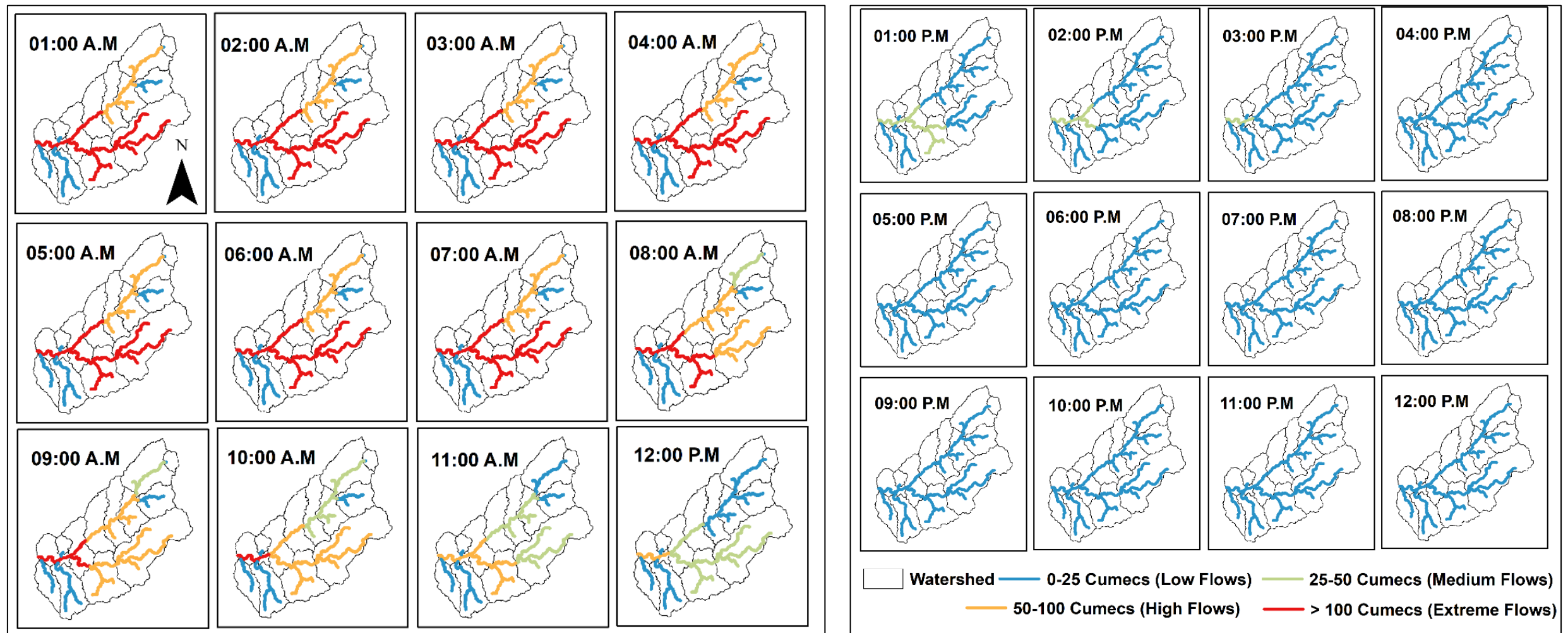
Temporal Downscaling



Peachtree Creek, Atlanta, GA

- Prediction of multi-temporal downscaled data at ungauged stations using adaptive emulator concepts.
- Single interfusion algorithm for temporal downscaling of hydrological variables and calibration of physical models.
- Hybridization of physical and emulator models to provide accurate daily to sub-daily scale outputs.

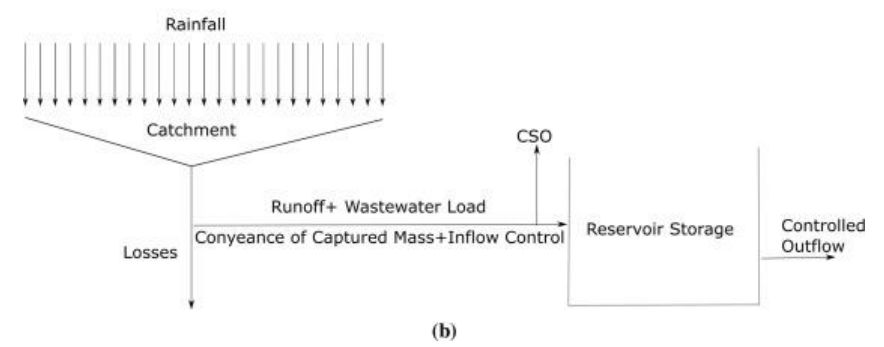
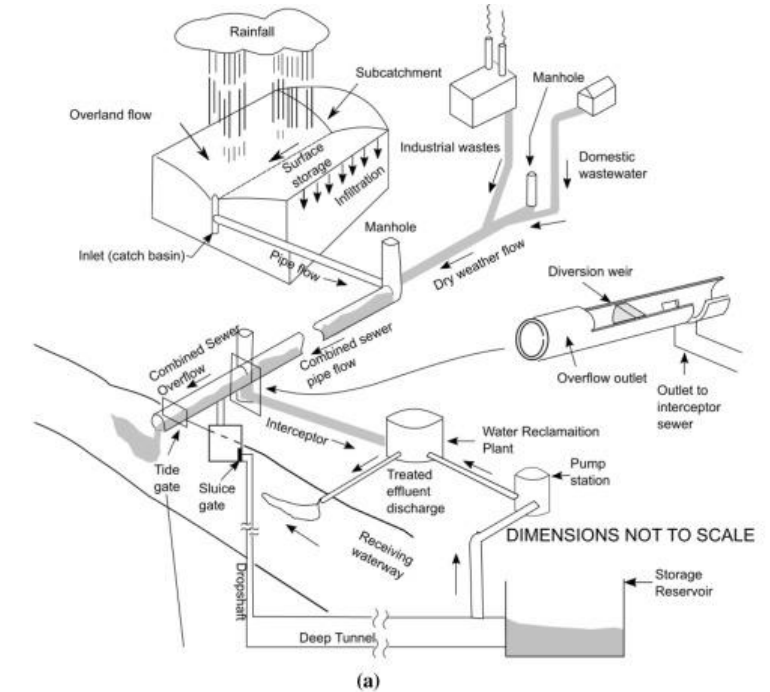
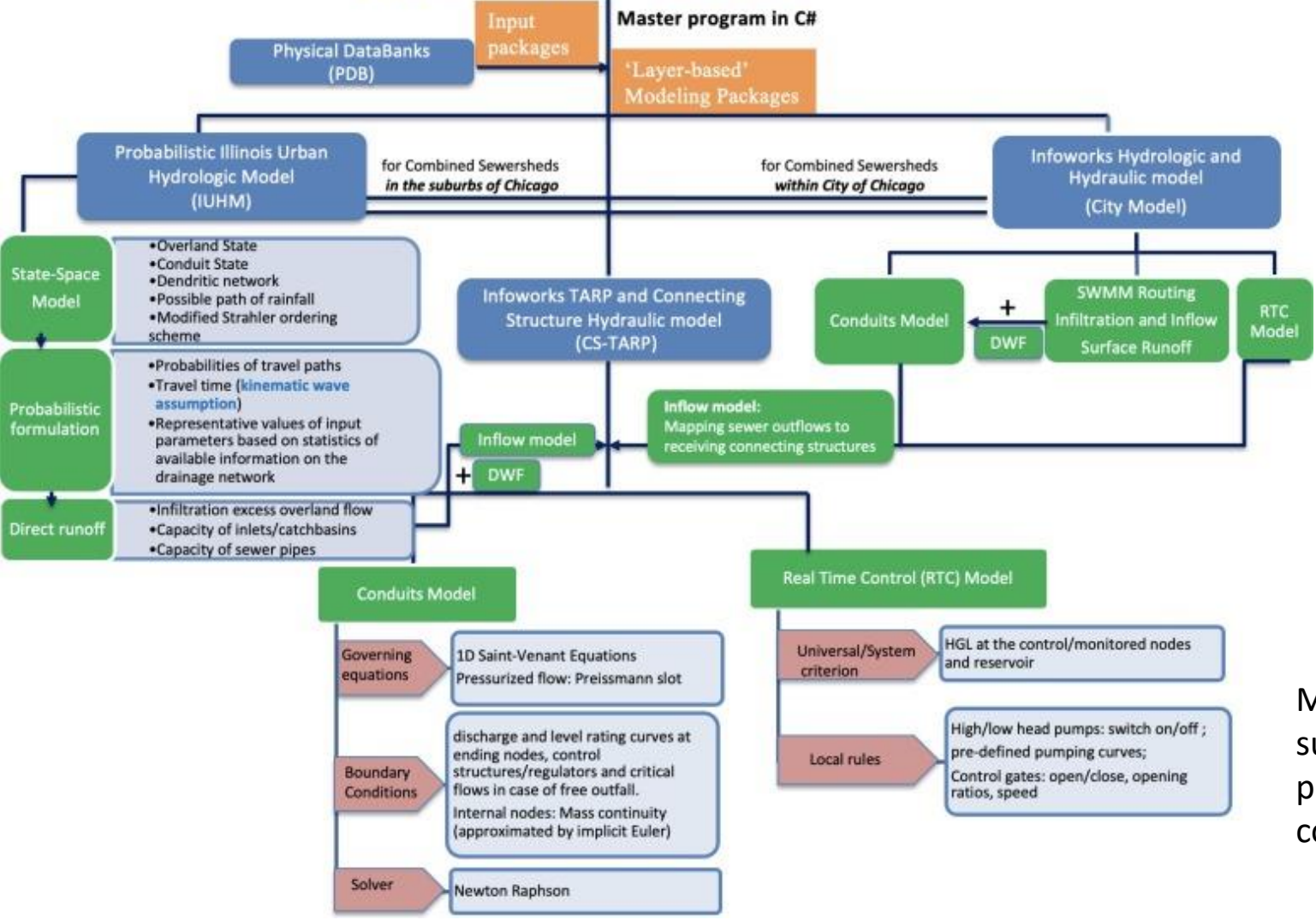
Temporal Downscaling



Decentralized/Combined Sewer System

Combined Sewer System

METROFLOW

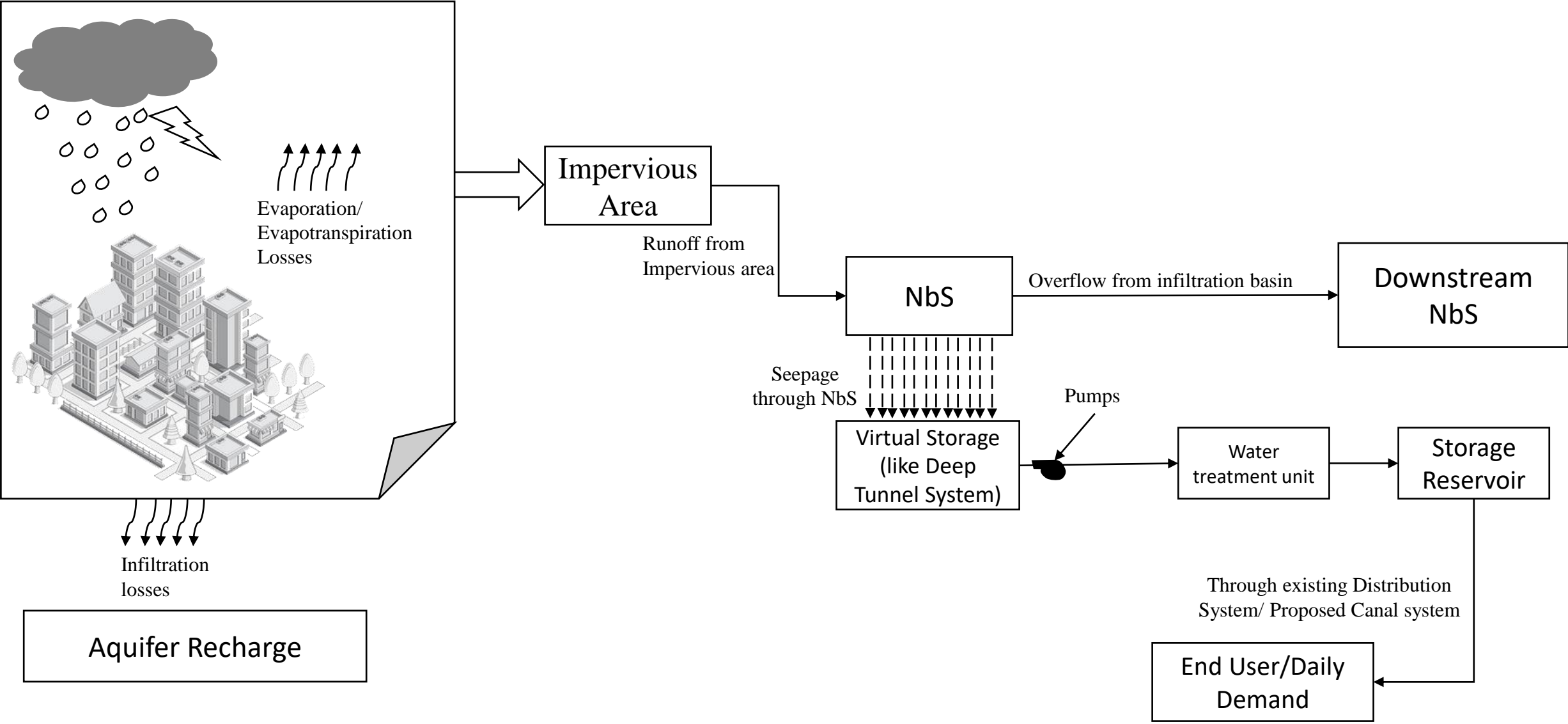


MetroFlow - City's overall urban drainage system: surface and near-surface sewers, interceptors (i.e., the pipes that divert sewage to water reclamation plants), connecting structures and deep tunnel systems.

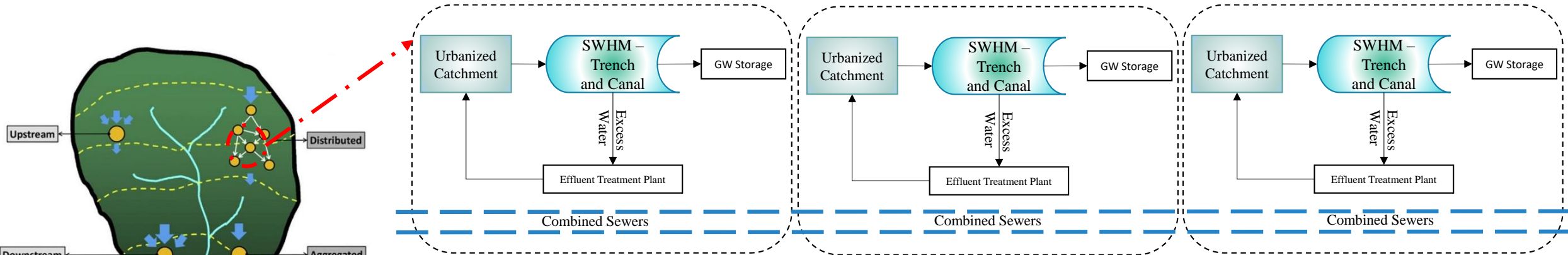
Decentralized/Combined Sewer System

An example of Vellore, India....

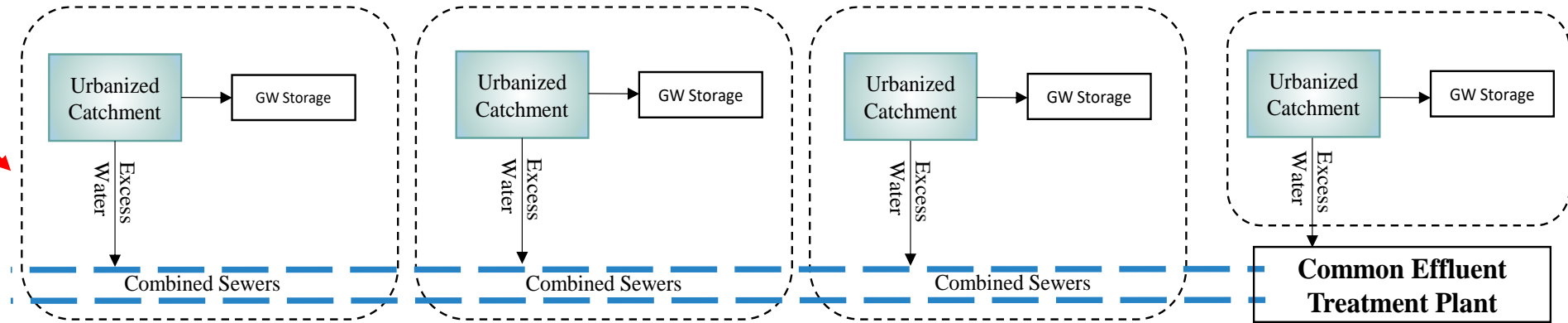
Decentralized Sewer system



Decentralized/Combined Sewer System

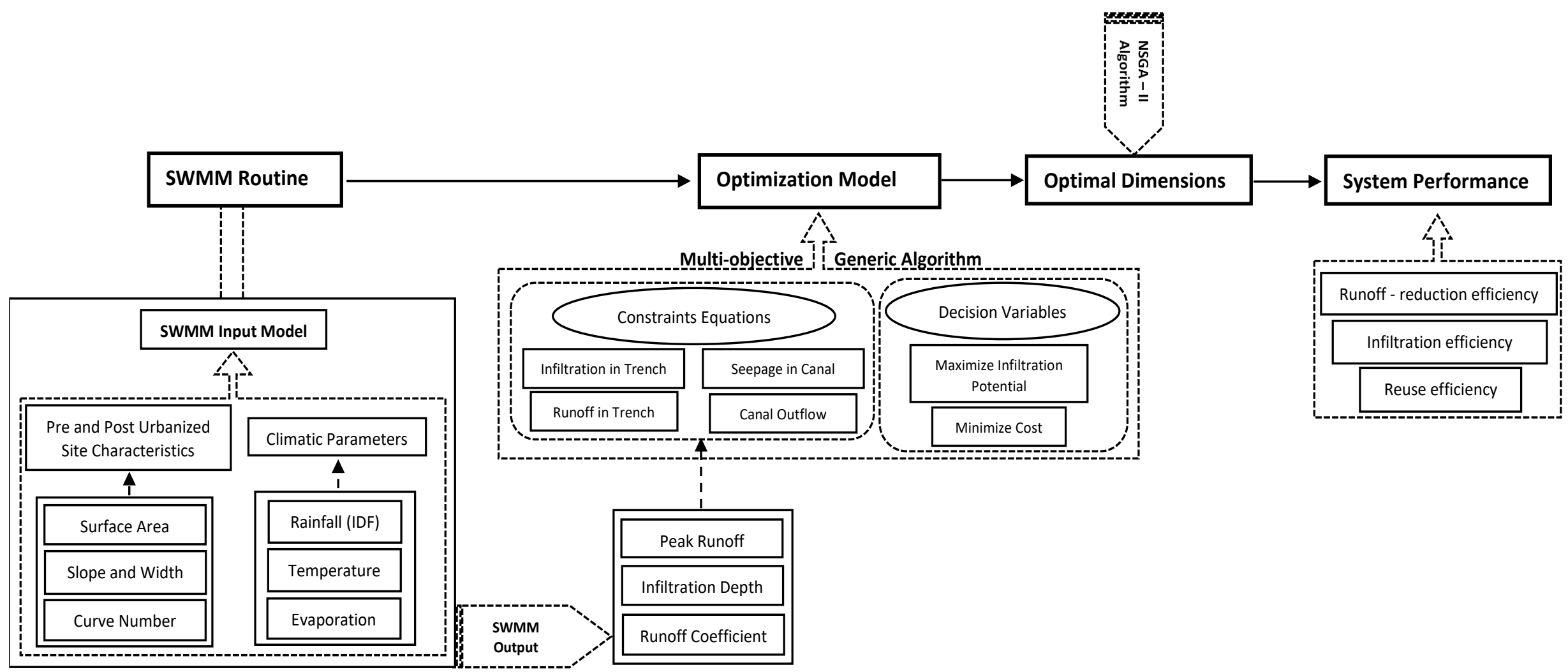


S3/S4 – Decentralized System with Effluent Treatment Plant



S1/S2 - Existing Sewers with Common Effluent Treatment Plant

Decentralized/Combined Sewer System



Decentralized/Combined Sewer Ssystem

Overall Efficiencies for each Scenario

Design Efficiency (%)	Scenarios			
	S1	S2	S3	S4
E_{fp}	51	59	65	81
E_{rr}	39	31	27	-
E_{ww}	100	18.3	14	-
E_{pw}	26	31.4	34.2	34.2
E_{rmax}	39.57	30.86	23.45	58

Efficiencies for Varying Urbanization

Design Efficiency (%)	NbS Scenarios			
	S3	S4	S3	S4
Urban (%)	5.18		56.43	
E_{fp}	84	82	65	45
E_{rr}	16	19	39	50
E_{rmax}	18	21	42	51

Cost Benefit Analysis for each Scenario

Parameters	Scenarios			
	S1	S2	S3	S4
Volume of Water Supplied to WTP Million liters (million gallons)	250.49 (66)	44.75 (11.82)	35.21 (9.3)	36.47 (9.6)
Capital Cost (million Rs)	9.09	1.62	1.28	1.15
O & M Cost (million Rs)	2.30	0.41	0.32	0.29
Land Requirement (m ²)	6656.75	1189.30	935.64	1029.20
Land Cost (million Rs)	0.69	0.12	0.10	0.10

\$1 = Rs 83.23

Nature-based Solutions (NbS) to Mitigate Extremes

NbS to Mitigate Extremes



Critical Facilities



Tourism



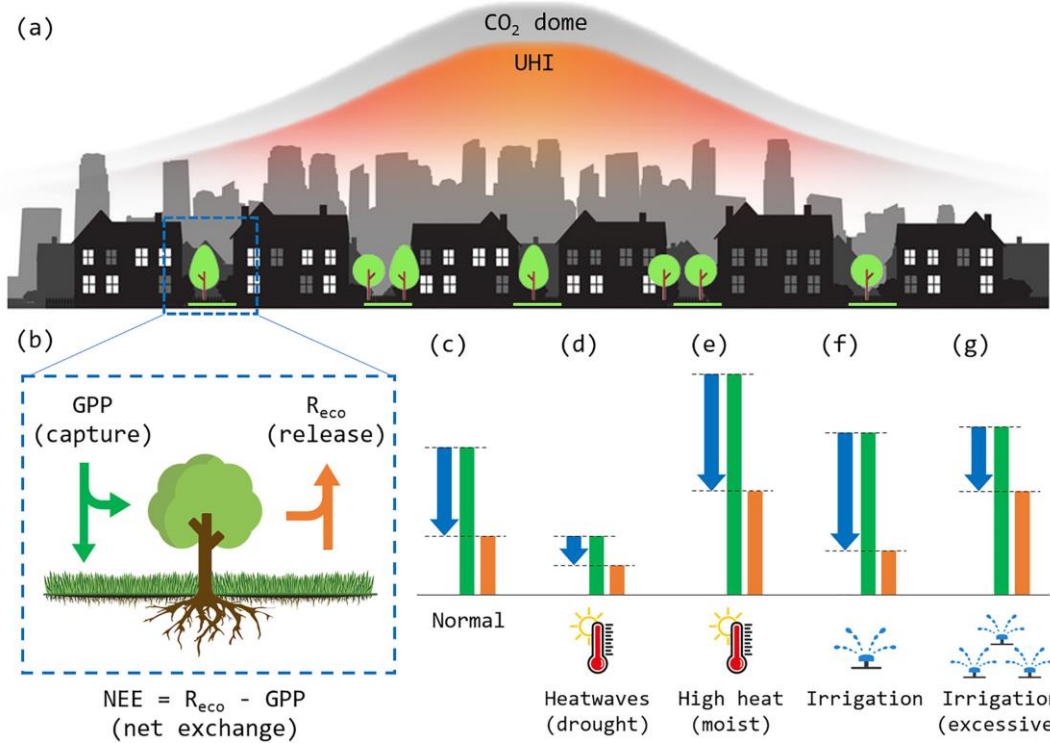
Ecosystems and Wildlife



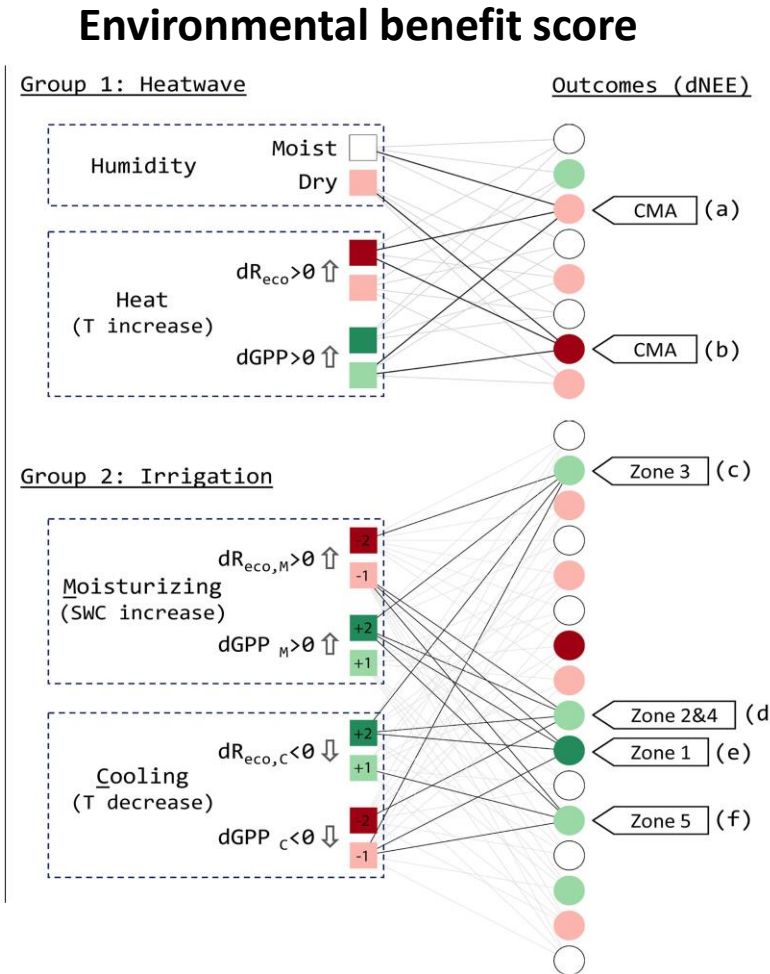
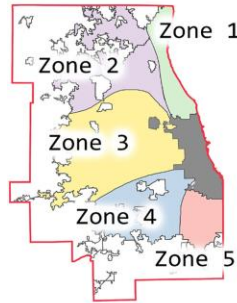
Projected changes to water quantity and quality



NbS in Carbon Neutrality



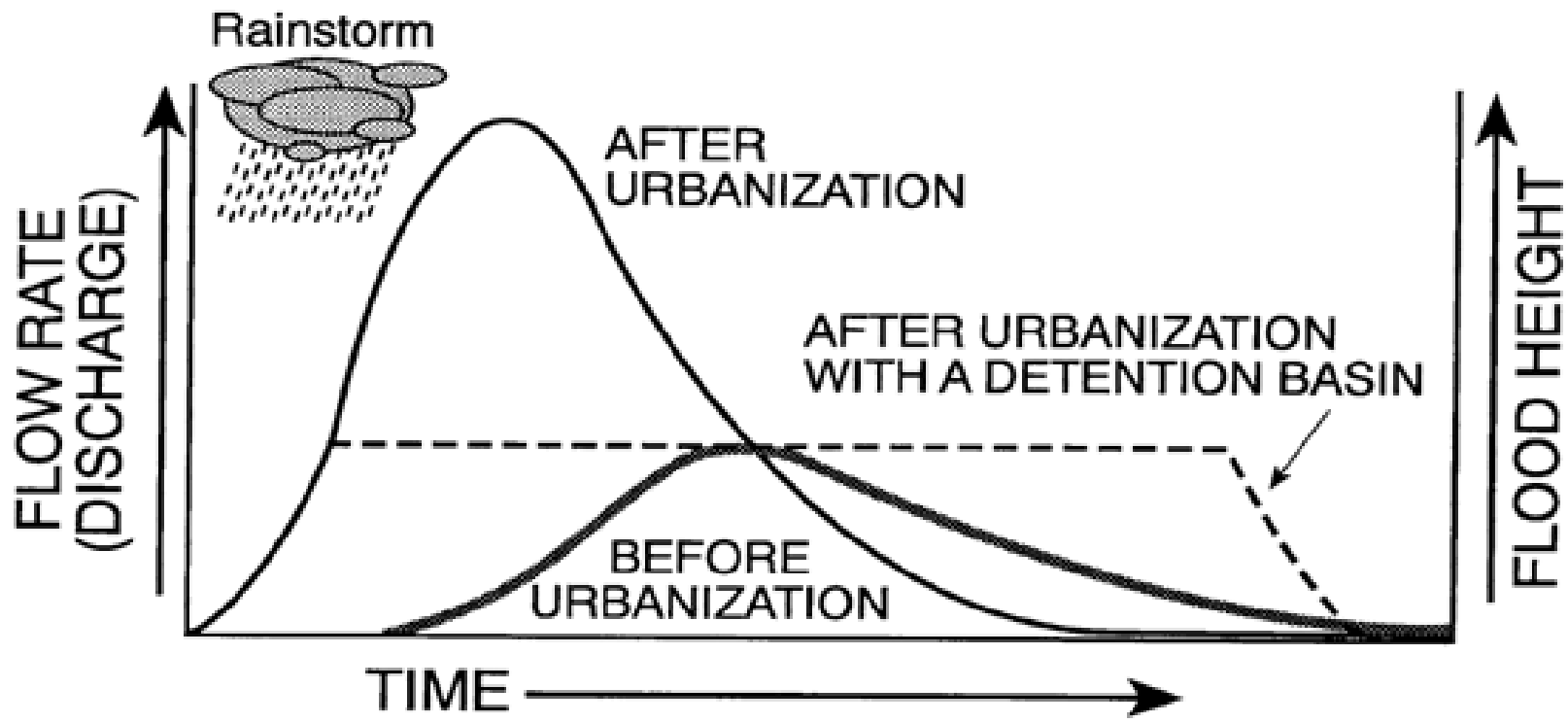
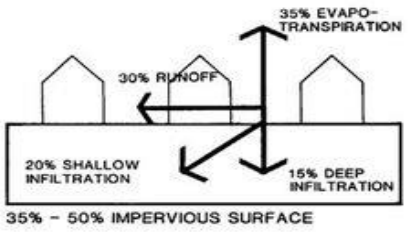
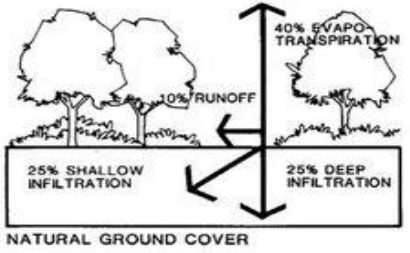
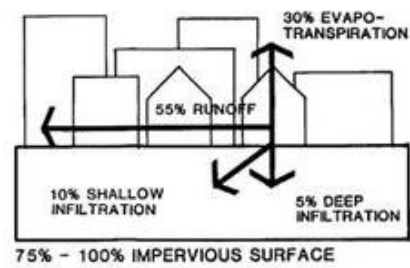
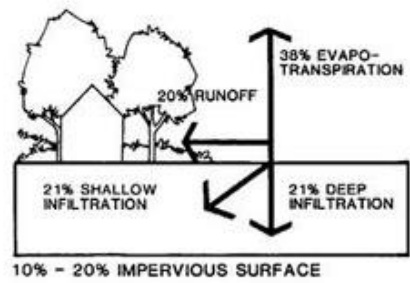
- Best, EBS +2
- Good, EBS +1
- Neutral, EBS 0
- Bad, EBS -1
- Worst, EBS -2



Li et al., *J. Adv. Model. Earth Syst.* (2023)

- Vegetation plays a significant role in the city's carbon portfolio.
- Landscaping management has the potential to reduce carbon emissions significantly.
- High temperature caused by heatwaves reduces the CO₂ sink power from vegetated land by 39% of traffic emissions.
- Urban irrigation: mitigate heat and increases carbon capture efficiency by 35%

Effect of NbS on Runoff Hydrographs



Advances in Water Resource and Protection (AWRP) Volume 2 Issue 2, April 2014

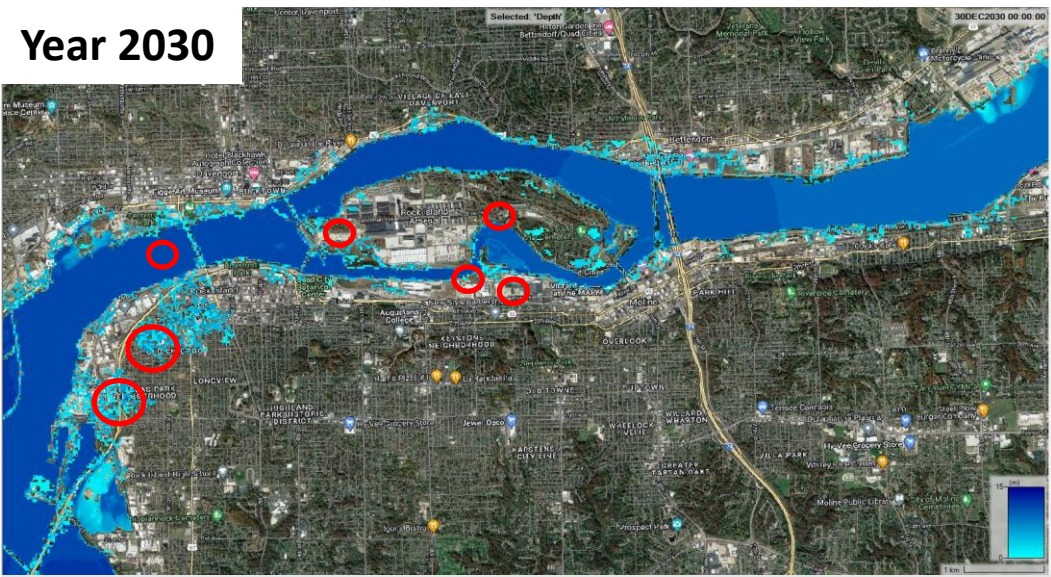


An example....

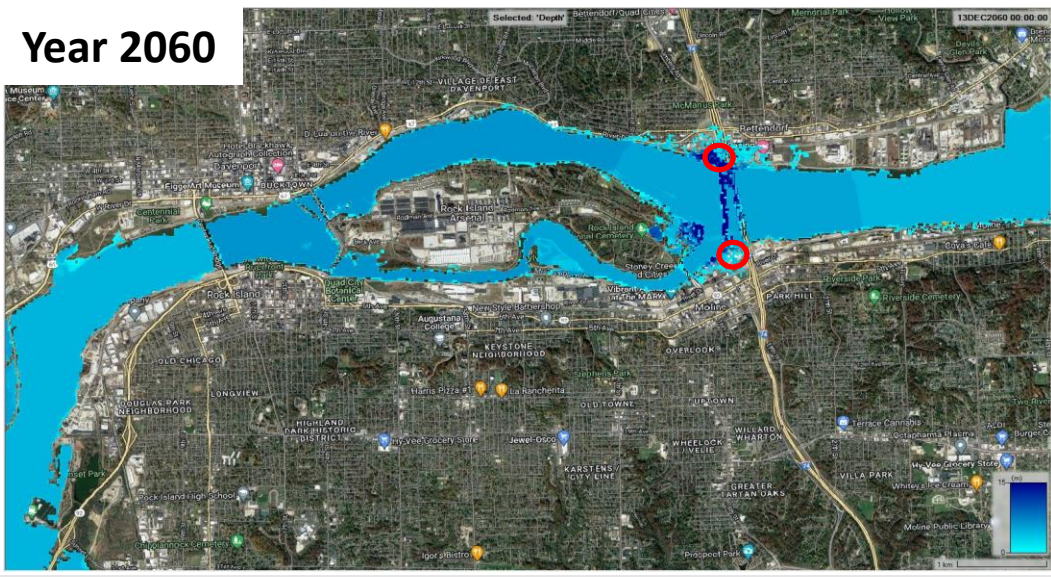
Flood mitigation strategies in QUAD cities using NbS

Flood Inundation Maps for QUAD Cities – Before NbS

Year 2030

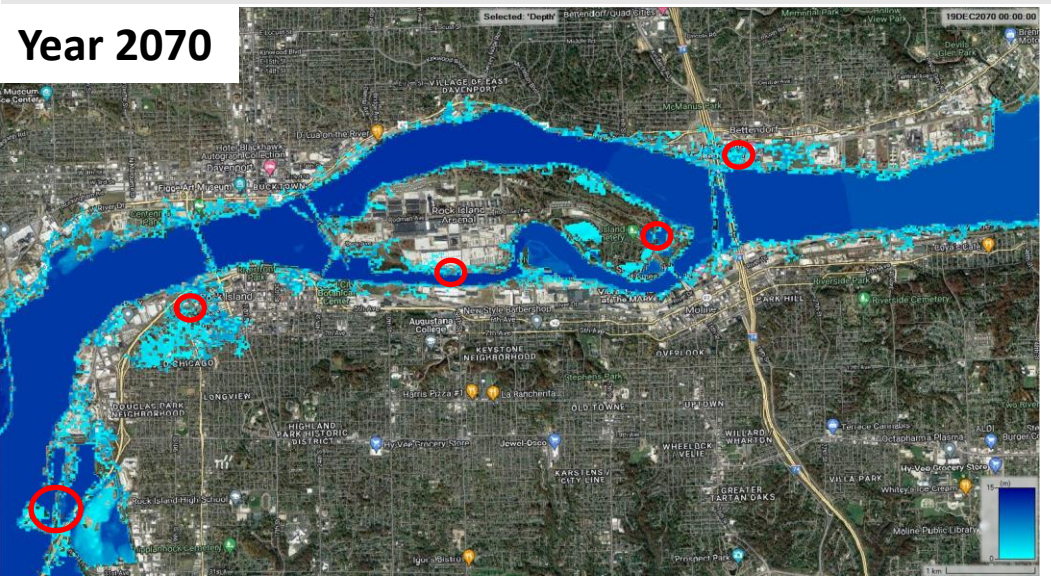


Year 2060

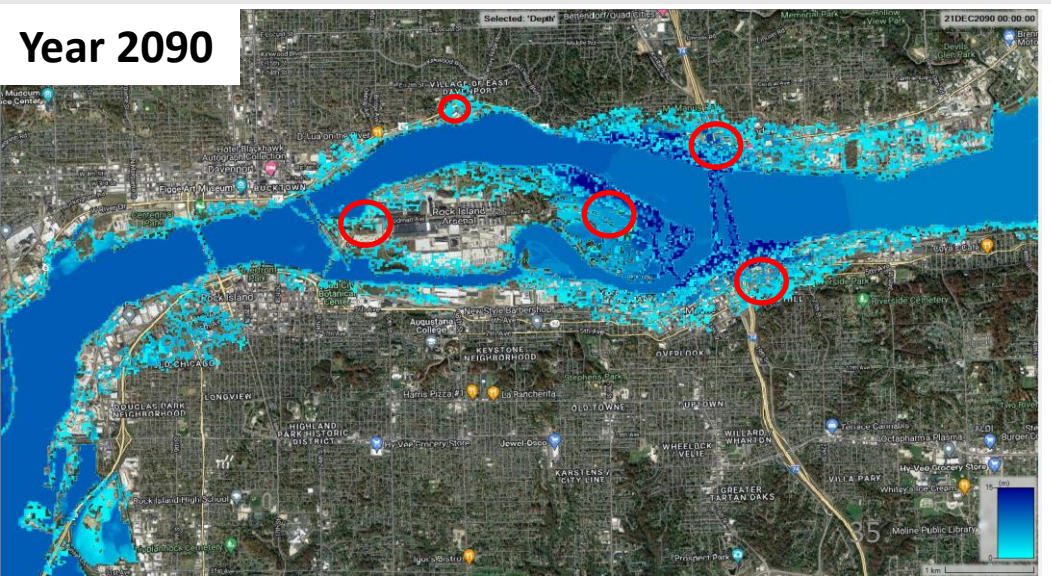


No additional NbS Implemented in QUAD City Region – Operating policy same as historical period

Year 2070



Year 2090

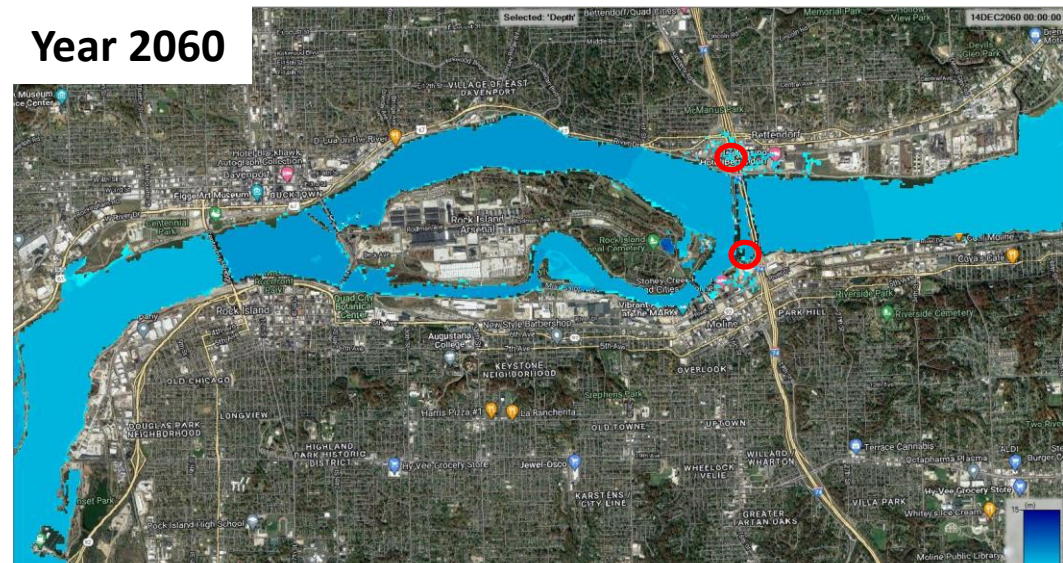


Flood Inundation Maps for QUAD Cities – After NbS

Year 2030

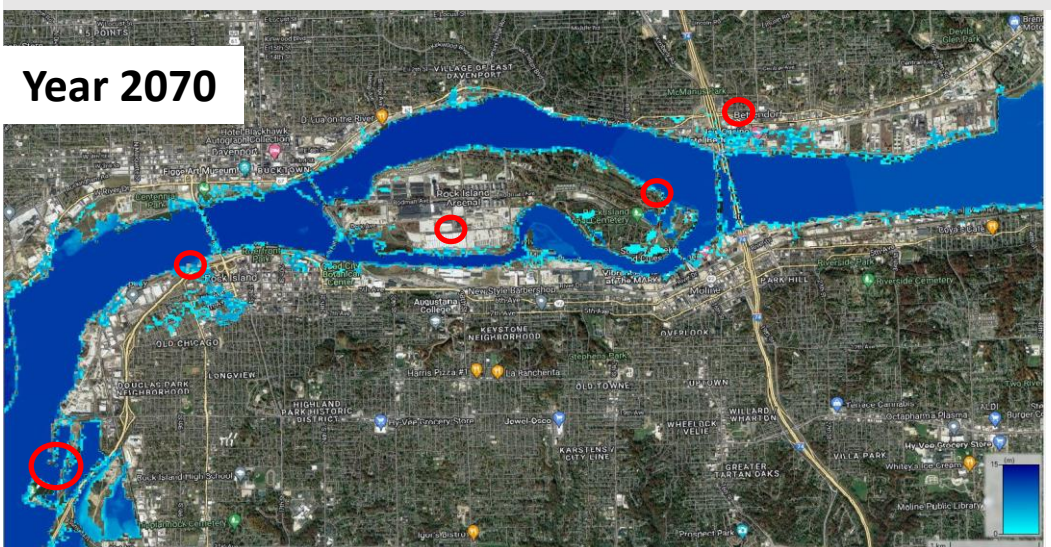


Year 2060

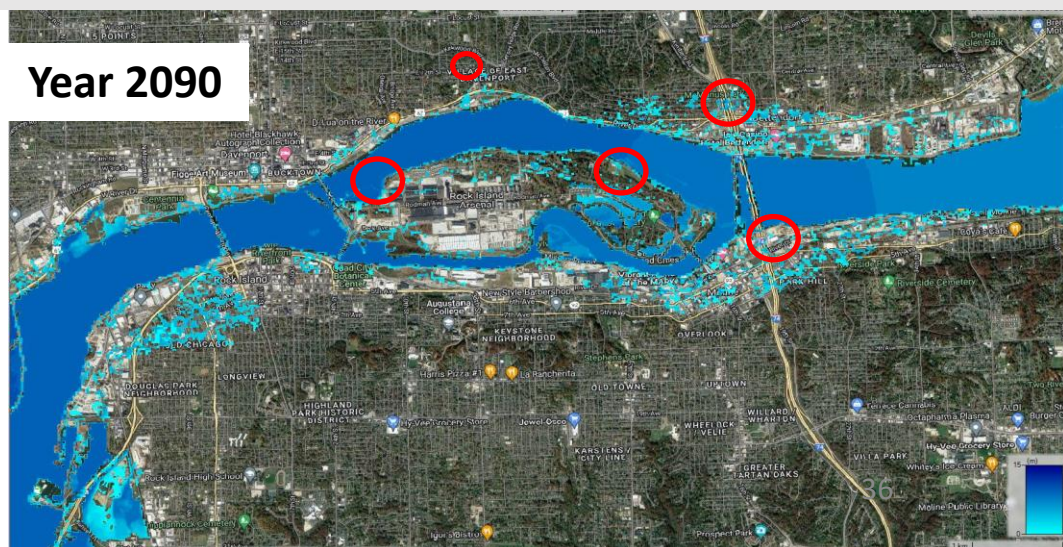


Riparian buffers, Wetlands, Green Roofs - NbS Implemented in QUAD City Region – Operating policy same as historic period

Year 2070



Year 2090



Proposed NbS Systems

City Name	Feature Impacted	NbS Proposed	Featured Secured
Rock Island	Developed, High, Medium and Low Intensity Pasture Woody Wetlands Cultivated Crops Deciduous Forest	Expansion of Nahant Marsh General Places Permeable Pavements Green Roofs Prairies...	Developed High Intensity Pasture Woody Wetlands Cultivated Crops Deciduous Forest
Davenport	Herbaceous Developed, Low and Medium Intensity Deciduous Forest Woody Wetlands	Restoring Wetlands Open Spaces Community Garden Creek Parks.....	Developed, Low Intensity Deciduous Forest Woody Wetlands
Bettendorf	Open Water Developed, Low and Medium Intensity Mixed Forest	Open Gardens Green Roofs Parks and open spaces	Developed, Low and Medium Intensity Mixed Forest
East Moline	Developed, Low and Medium Intensity Deciduous Forest	Parks and open spaces Green Roofs	Developed, Low and Medium Intensity

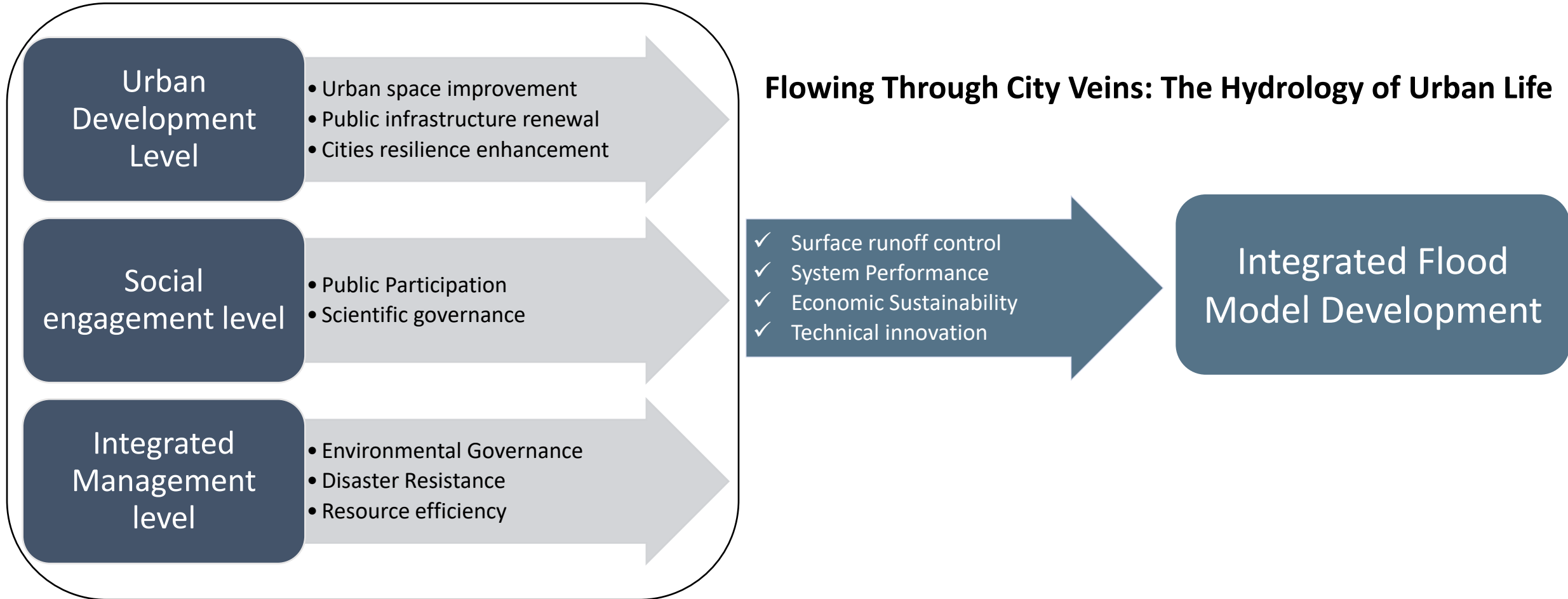
An example....

Using NbS in response to climate change in small-scale urban catchments (Vellore, India)

<https://www.tandfonline.com/doi/full/10.1080/02626667.2023.2239797>

Sustainable Flood Risk Management

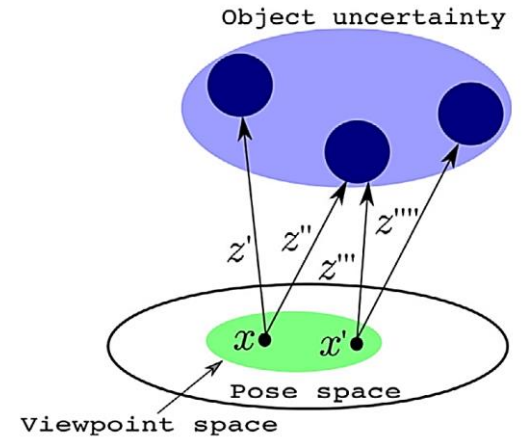
Sustainable Flood Risk Management



Stakeholder Feedbacks



Stakeholder Viewpoints



Cognitive

- Knowledge Limitation
- Approximations
- Viewpoints Differences
- Terminology Imprecision
- Disagreement Among Teams

Organization

- Other Projects
- Organization Priorities
- Organization Policies
- Tools and Technologies

Economic Levels

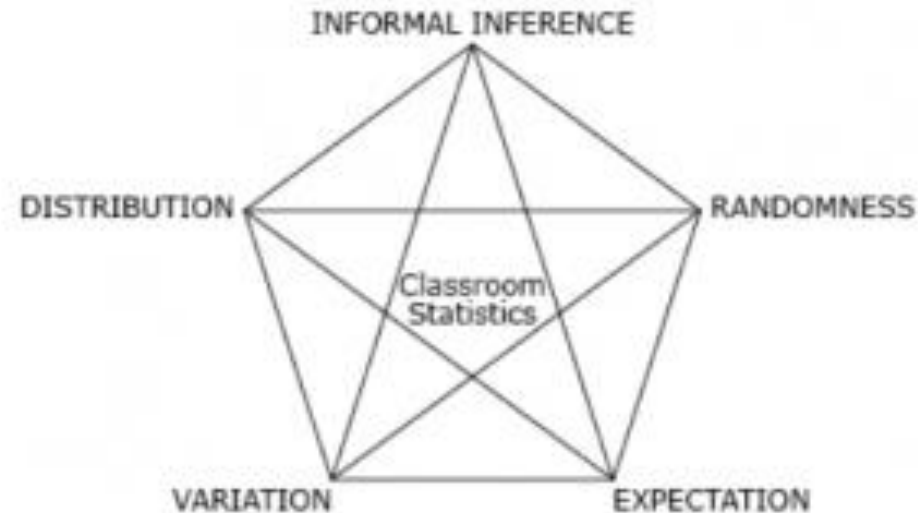
- Literacy
- Income Levels
- Employment Status
- Residential Status

Variation

- Natural Variation
- Aging
- Environment
- Measurement Errors
- Scaling Issues

An example...

How we integrate feedbacks/viewpoints surveys to address supply water to residents?



Outcome of surveys

Results summarized based on family size, income group, monthly water bill

Additional water supply desired	Willingness to pay for additional water (Rs/1000 lpd)	Break-up of response based on family size			Total numbers
		Small (1 – 2)	Medium (3 – 5)	Large (>5)	
30 lpcd	4.5	249	392	202	843
55 lpcd	7.86	142	332	142	617
100 lpcd	14.3	119	368	107	593
130 lpcd	18.6	89	24	18	131
Additional water supply desired	Willingness to pay for additional water (Rs/1000 lpd)	Break-up of response based monthly water bill			Total numbers
		0 – 250 (Rs/month)	250 – 500 (Rs/month)	> 500 (Rs/month)	
30 lpcd	4.5	384	74	384	841
55 lpcd	7.86	258	74	258	590
100 lpcd	14.3	243	140	243	627
130 lpcd	18.6	52	22	52	125
Additional water supply desired	Willingness to pay for additional water (Rs/1000 lpd)	Break-up of response based on income group			Total numbers
		Low (0.75 – 3 lpa)	Medium (3 – 5 lpa)	High (> 5 lpa)	
30 lpcd	4.5	306	288	306	900
55 lpcd	7.86	166	166	166	498
100 lpcd	14.3	227	201	227	655
130 lpcd	18.6	26	79	26	131

No consensus reached!!

What can be done?

Proposed Solution → use “fuzzy” approach to reach a consensus

Let us consider volume of water supplied as a “fuzzy variable”

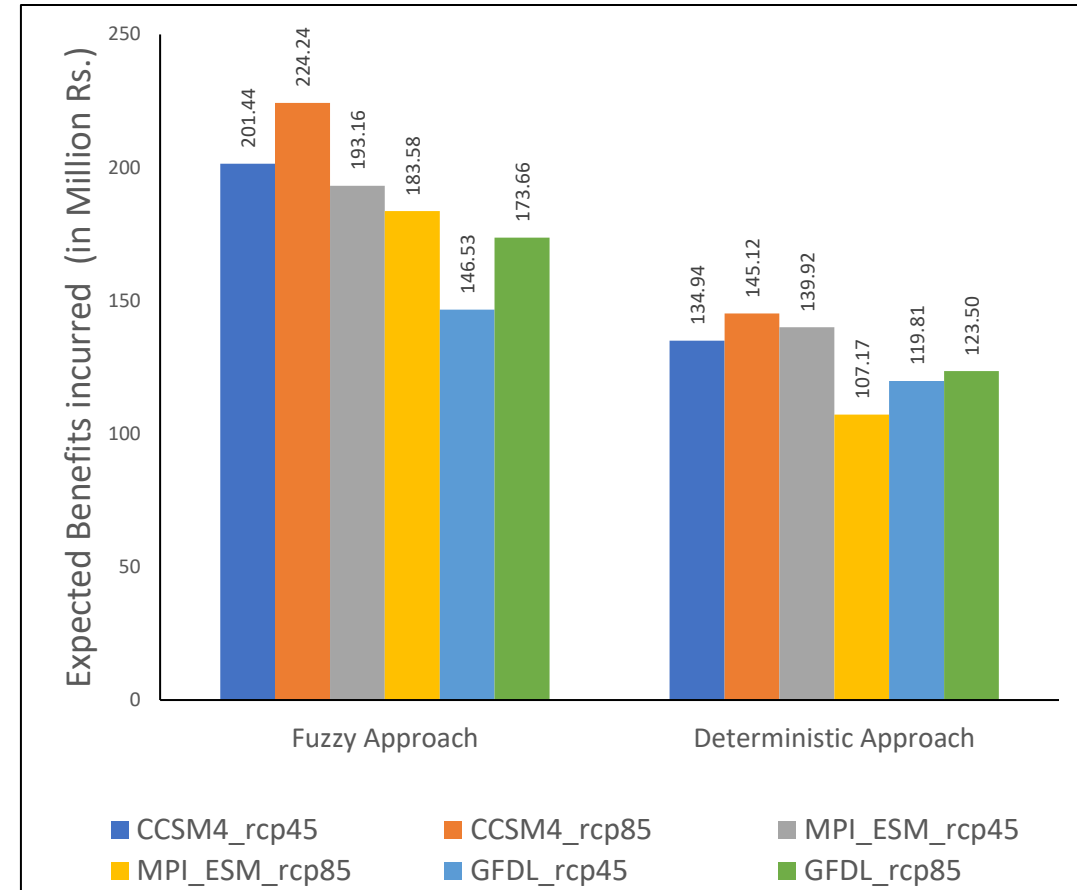
Find benefits obtained from fuzzy approach when compared to deterministic approach

Cost Benefit Analysis

Fuzzy Variable

$$Expected\ benefits(NB_A) = \sum_{t=1}^T C_{w,i} \times \check{V}_{p,i,t}$$

Notation	Definition	Formula	Units
NB_A	Annual net benefits	$c_w V_p$	Rs
CC_{pond}	Capital cost of the percolation pond	$275LD(B + D)$	Rs/m ³
C_{M_pond}	Annual maintenance cost for pond	6% of CC_{pond}	Rs/m ³ /year
$CC_{conveyance}$	Capital cost of conveyance system	152.9lb	Rs/m ³
$C_{M_conveyance}$	Annual maintenance cost of conveyance system	6% of $CC_{conveyance}$	Rs/m ³ /year
$CC_{land\ cost}$	Land acquisition cost for pond	$10324L(B + 2D)$	Rs/m ²
$CC_{conv\ land\ cost}$	Land acquisition cost for the conveyance system	10324lb	Rs/m ²
CC_{SR}	Capital cost of service reservoir	$10324 * \frac{\pi D^2}{4}$	Rs/m ³
CC_{pump}	Capital cost of the pump to be installed	$11050P^{0.594}$	Rs
$CC_{treatment\ plant}$	Capital cost of water treatment plant	14 Lakhs	Rs/m ³
$C_{treatment}$	Annual water treatment cost	$0.0063(T_{inflow} - T_{outflow})$	Rs/m ³
PF	Present worth factor	$\frac{r(1+r)^t}{(r+1)^t - 1}$	
$C_{w,i}$	Benefit obtained to supply water/lpcd		Rs



Vision for Urban Cities

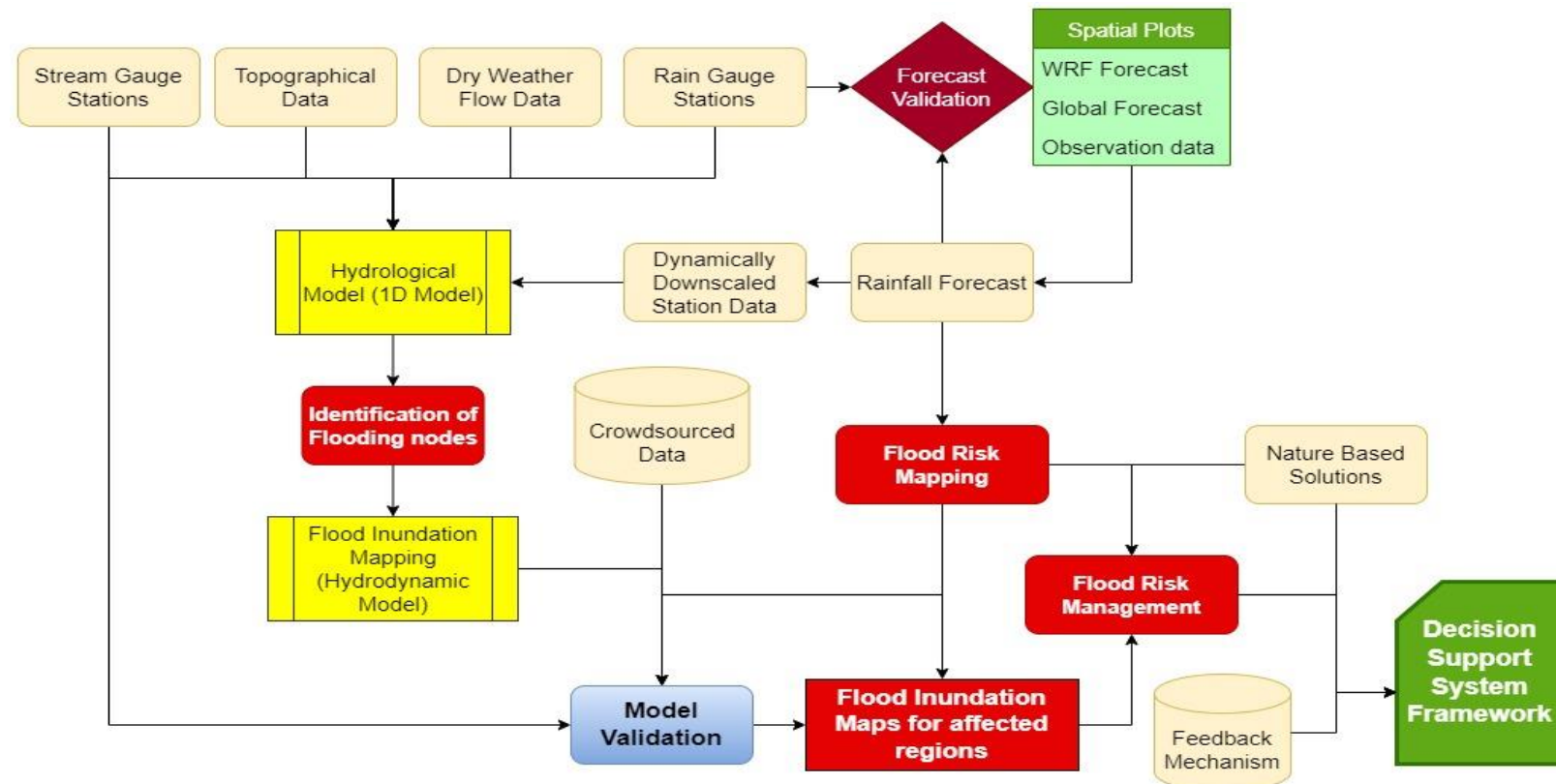


Future Scope

- Early Warning System/Dashboard at Street Scale
- Decision support system for end users to identify most reliable NbS solution
- “What-if” scenarios and uncertainty in decision making for new infrastructure
- Life cycle assessment of existing and new infrastructure using AI/ML approaches
- NbS impacts on CAWS and deep tunnel system
- Climate change impacts: hydraulic structure-induced flows/hydraulic resistance

Early Warning System/Dashboard

- ✓ Designing infrastructure in the face of climate change: existing infrastructure and potential climate risks
- ✓ Decision support system for early warning flood forecast system
- ✓ Engineered and non-engineered solutions to mitigate flooding in urban cities.



Thank
you 

