Metropolitan Water Reclamation District of Greater Chicago

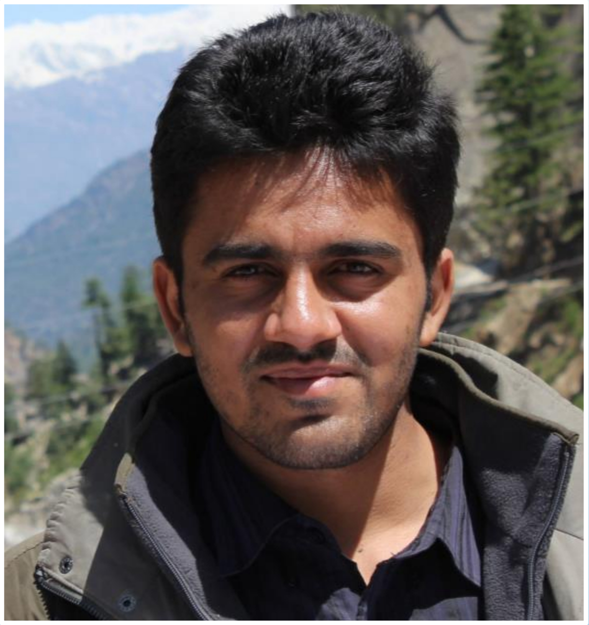
Welcome to the October Edition of the 2023 M&R Seminar Series

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

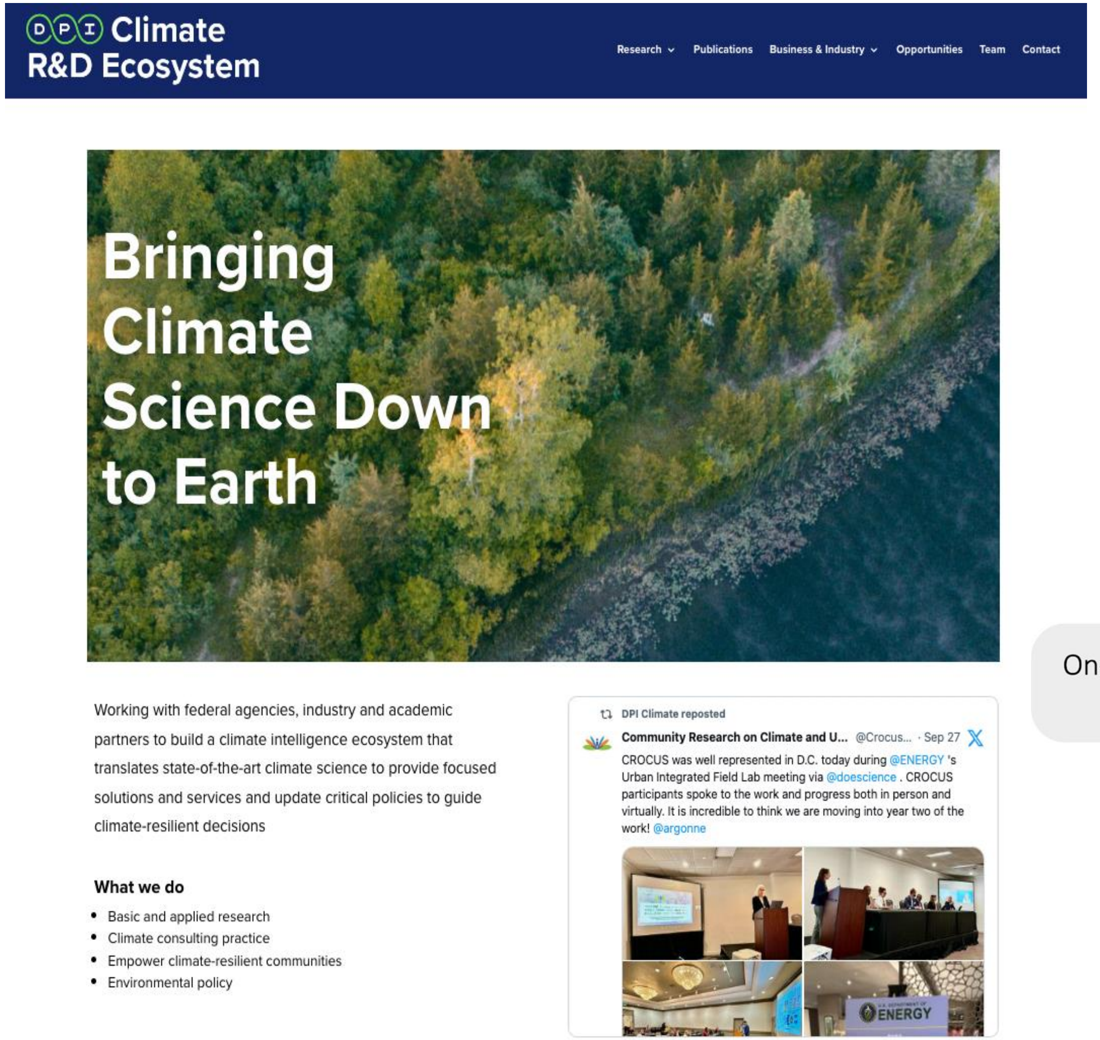
Key Contents

- 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

Extreme Event + **Hydrologic Modelling** = **Regional Hydrology** + **Sustainable Measures** = **Attenuation in Extremes** + **Feedbacks** + **Localized Survey** = **Net Benefits** + **Uncertain Responses** = **Economic and Volumetric Reliability**

Climate Ecosystem at DPI

Translational ← Applied ← Fundamental



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

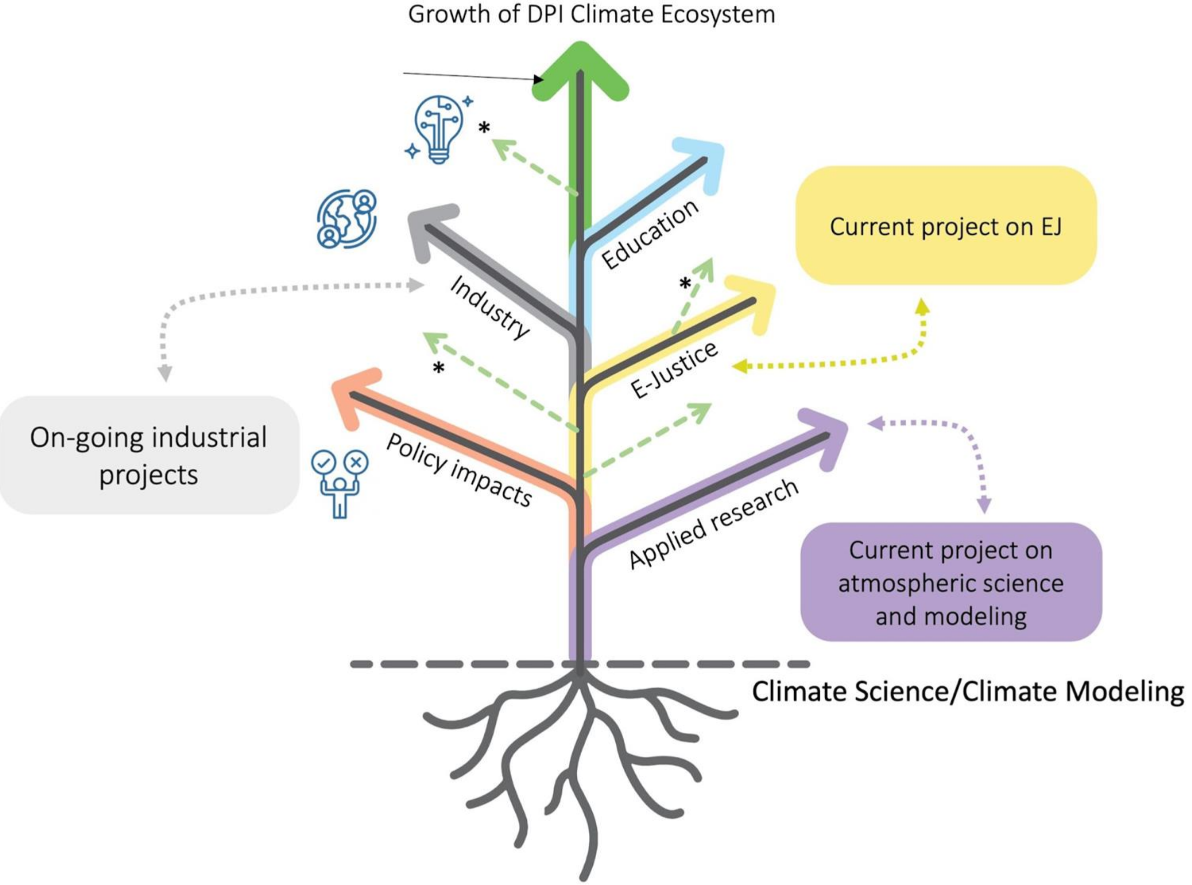
DPI Climate reposted

Community Research on Climate and U... @Crocus... · Sep 27

CROCUS was well represented in D.C. today during @ENERGY 's Urban Integrated Field Lab meeting via @doescience . CROCUS participants spoke to the work and progress both in person and virtually. It is incredible to think we are moving into year two of the work! @argonne

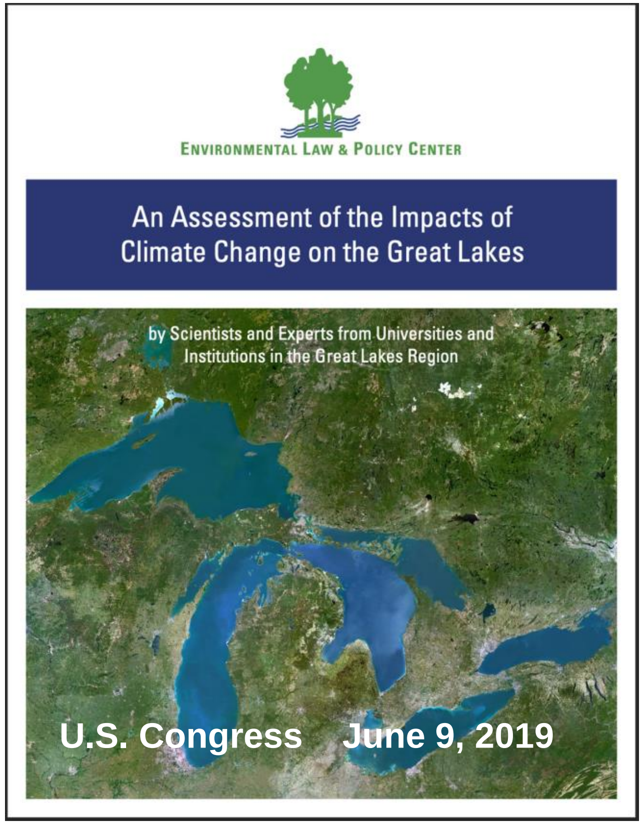
https://www.climate-dpi.org/

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

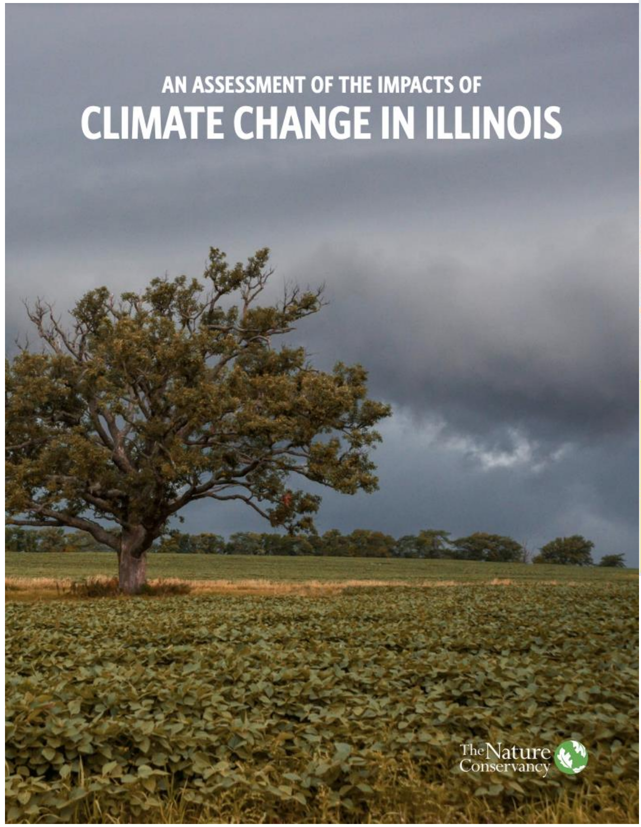


ENVIRONMENTAL LAW & POLICY CENTER

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

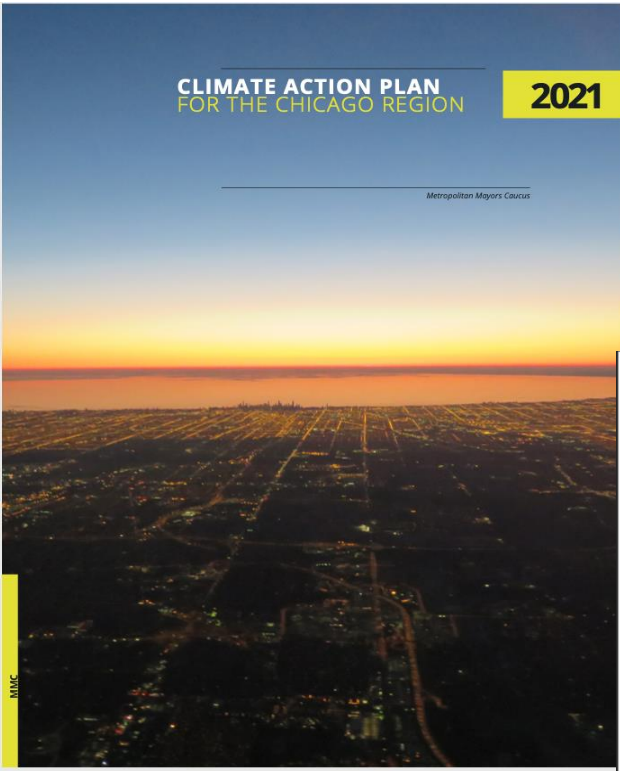
by Scientists and Experts from Universities and
Institutions in the Great Lakes Region

U.S. Congress June 9, 2019



AN ASSESSMENT OF THE IMPACTS OF
CLIMATE CHANGE IN ILLINOIS

The Nature Conservancy

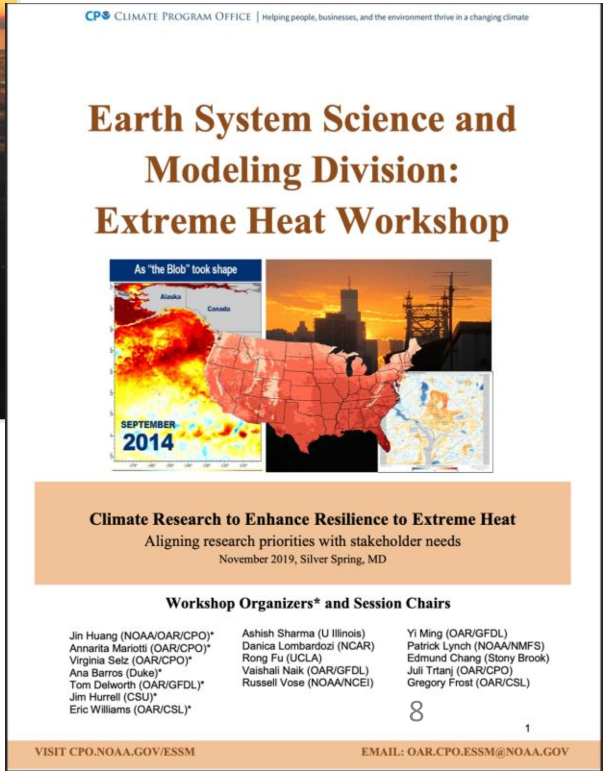


CLIMATE ACTION PLAN
FOR THE CHICAGO REGION

2021

Metropolitan Mayors Caucus

MMC



CP CLIMATE PROGRAM OFFICE | Helping people, businesses, and the environment thrive in a changing climate

Earth System Science and
Modeling Division:
Extreme Heat Workshop

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)*
Annarita Mariotti (OAR/CPO)*
Virginia Selz (OAR/CPO)*
Ana Barros (Duke)*
Tom Delworth (OAR/GFDL)*
Jim Hurrell (CSU)*
Eric Williams (OAR/CSL)*

Ashish Sharma (U Illinois)
Danica Lombardozi (NCAR)
Rong Fu (UCLA)
Vaishali Naik (OAR/GFDL)
Russell Vose (NOAA/NCEI)

Yi Ming (OAR/GFDL)
Patrick Lynch (NOAA/NMFS)
Edmund Chang (Stony Brook)
Juli Trtanj (OAR/CPO)
Gregory Frost (OAR/CSL)

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VISIT CPO.NOAA.GOV/ESSM
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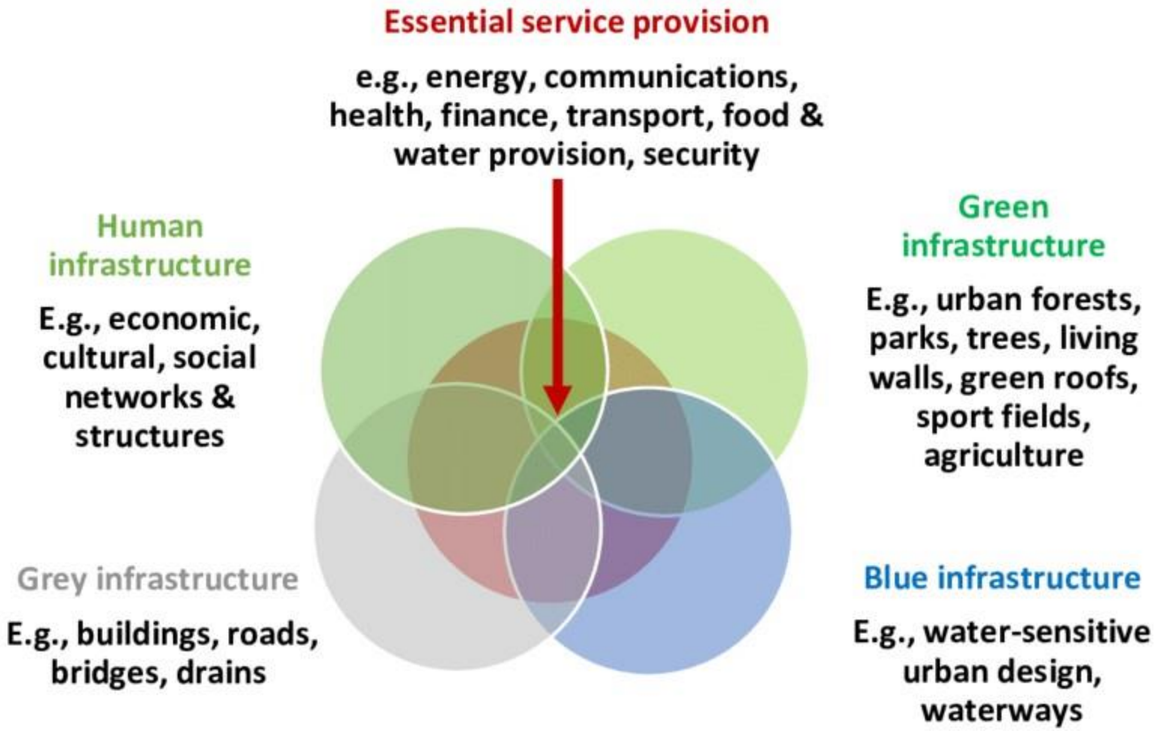
Introduction to Digital Twin

Digital Twin

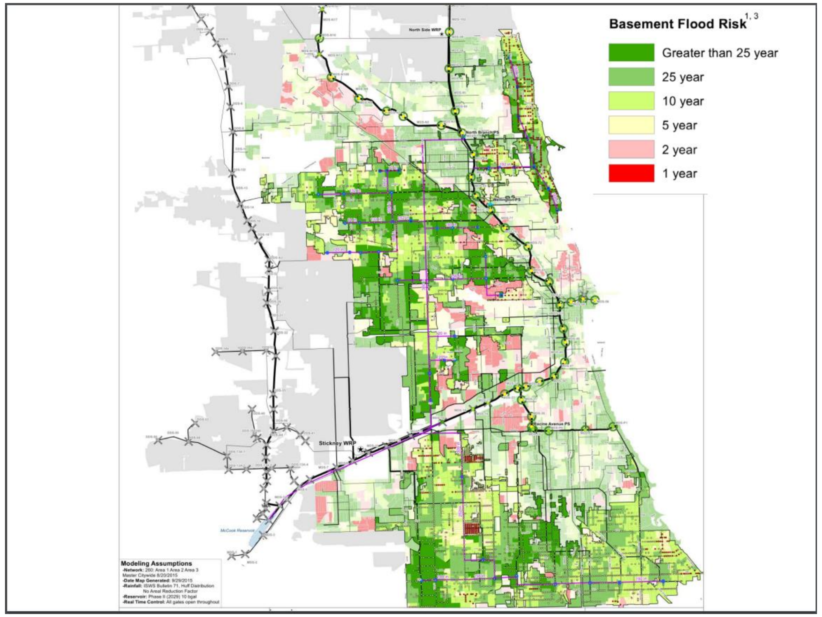


A digital twin is a virtual representation of a city, which can be used for the conception, the testing, the surveillance, the optimization, and the maintenance.

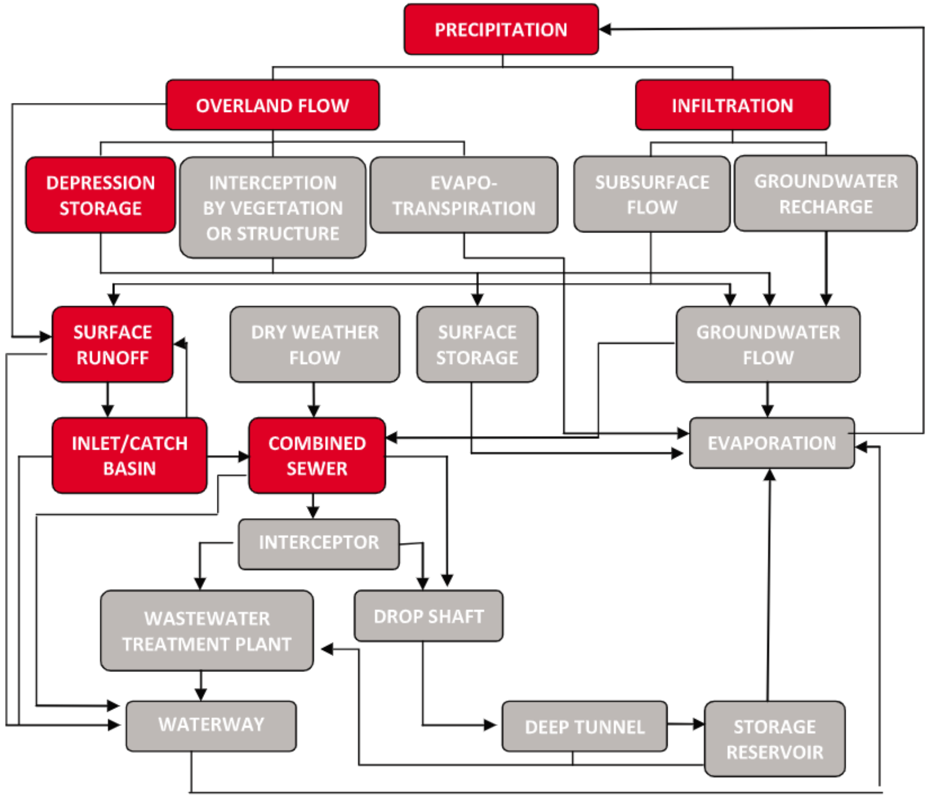
Young and John (2014)

Towards Digital Twin


https://github.com/enricolu/digital-twin



Source: MWRD



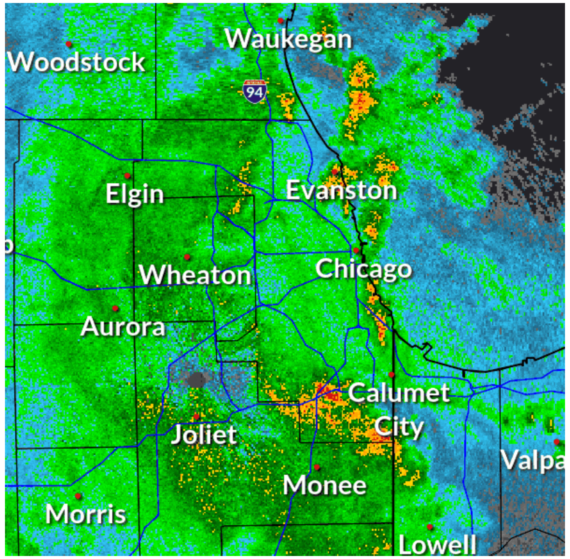
PRECIPITATION
OVERLAND FLOW
INFILTRATION
DEPRESSION STORAGE
INTERCEPTION BY VEGETATION OR STRUCTURE
EVAPO-TRANSPIRATION
SUBSURFACE FLOW
GROUNDWATER RECHARGE
SURFACE RUNOFF
DRY WEATHER FLOW
SURFACE STORAGE
GROUNDWATER FLOW
INLET/CATCH BASIN
COMBINED SEWER
EVAPORATION
INTERCEPTOR
WASTEWATER TREATMENT PLANT
DROP SHAFT
WATERWAY
DEEP TUNNEL
STORAGE RESERVOIR

Joshua and Arthur, 2011

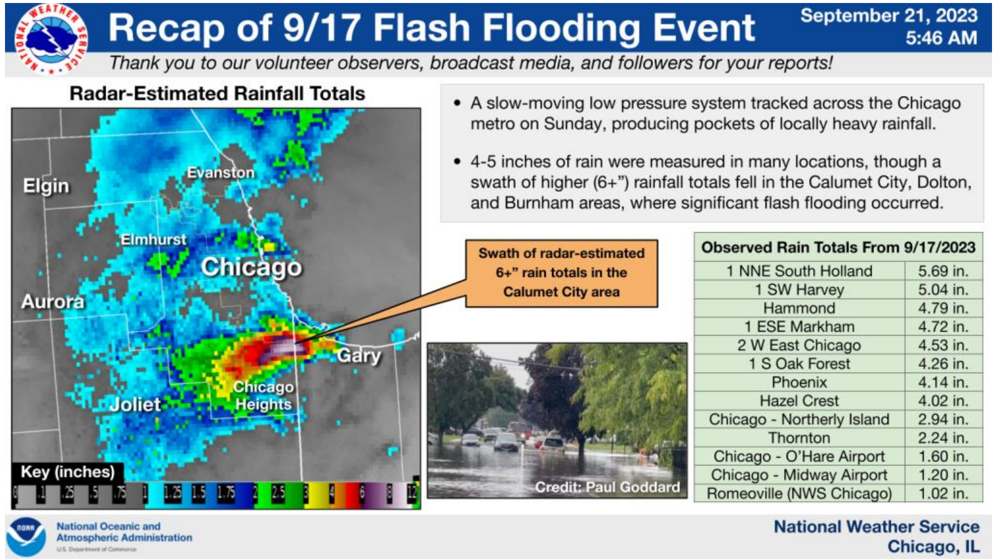
Tunnel and Reservoir Plan (TARP)

Source: MWRD

Digital Twin Benefits



NWS Radar Map



Recap of 9/17 Flash Flooding Event

September 21, 2023
5:46 AM

Thank you to our volunteer observers, broadcast media, and followers for your reports!

Radar-Estimated Rainfall Totals

- A slow-moving low pressure system tracked across the Chicago metro on Sunday, producing pockets of locally heavy rainfall.
- 4-5 inches of rain were measured in many locations, though a swath of higher (6+") rainfall totals fell in the Calumet City, Dolton, and Burnham areas, where significant flash flooding occurred.

Swath of radar-estimated 6+" rain totals in the Calumet City area

Credit: Paul Goddard

Observed Rain Totals From 9/17/2023	
1 NNE South Holland	5.69 in.
1 SW Harvey	5.04 in.
Hammond	4.79 in.
1 ESE Markham	4.72 in.
2 W East Chicago	4.53 in.
1 S Oak Forest	4.26 in.
Phoenix	4.14 in.
Hazel Crest	4.02 in.
Chicago - Northerly Island	2.94 in.
Thornton	2.24 in.
Chicago - O'Hare Airport	1.60 in.
Chicago - Midway Airport	1.20 in.
Romeoville (NWS Chicago)	1.02 in.

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

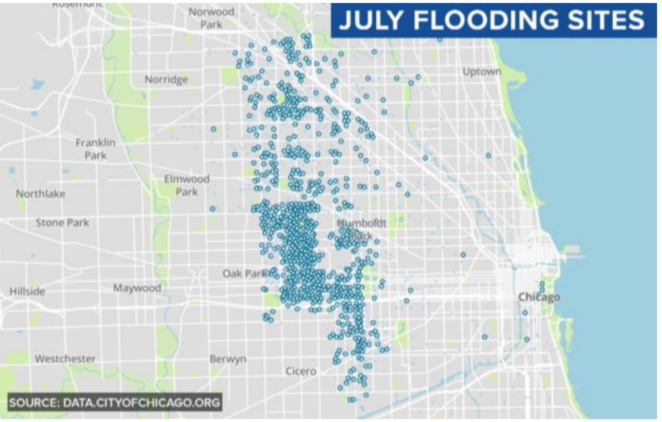
National Weather Service
Chicago, IL

Flood forecast by NWS

Flash Flooding
Suburbs of Chicago

Will street/building scale help?

Research hypothesis structure: stakeholders and ground level engineers experience

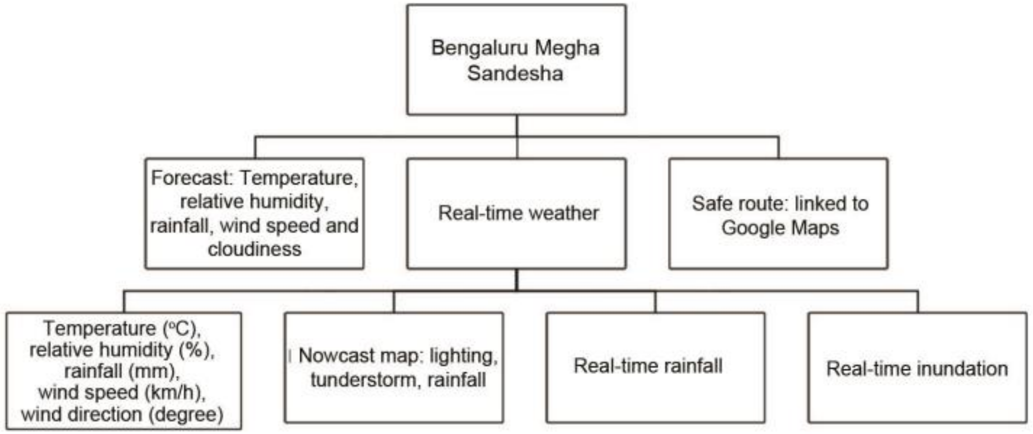


SOURCE: DATA.CITYOFCHICAGO.ORG

Post event relief

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

Towards Digital Twins



Bengaluru Megha Sandesha

Forecast: Temperature, relative humidity, rainfall, wind speed and cloudiness

Real-time weather

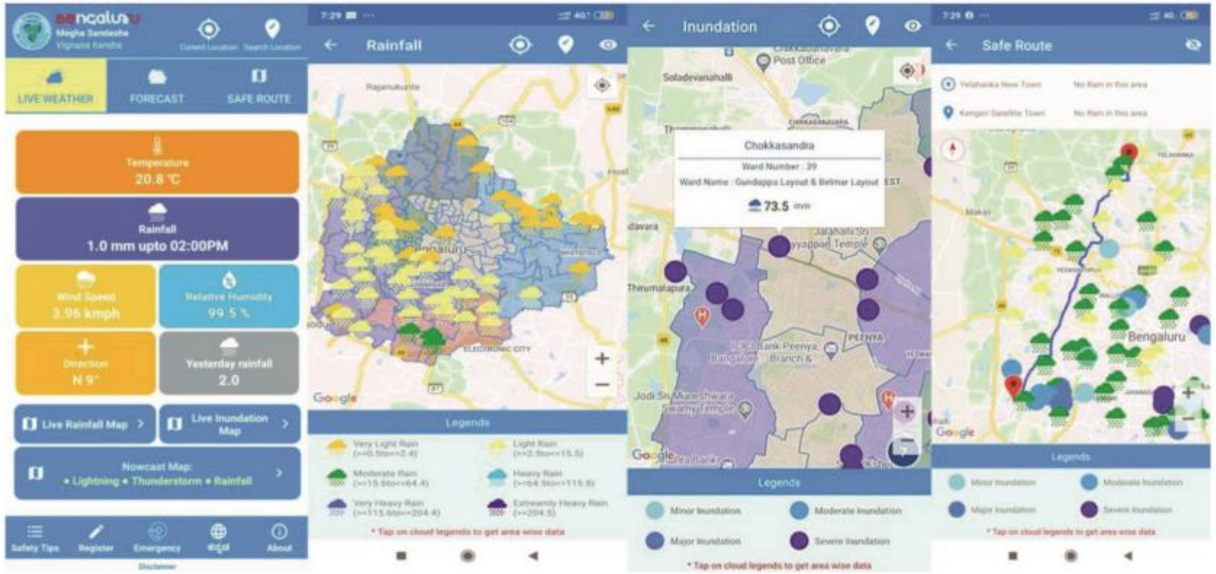
Safe route: linked to Google Maps

Temperature (°C), relative humidity (%), rainfall (mm), wind speed (km/h), wind direction (degree)

Nowcast map: lighting, tunderstorm, rainfall

Real-time rainfall

Real-time inundation



Temperature 20.8 °C

Rainfall 1.0 mm upto 02:00PM

Wind Speed 3.96 kmph

Relative Humidity 99.5 %

Direction N 9°

Yesterday rainfall 2.0

Chokkasandra

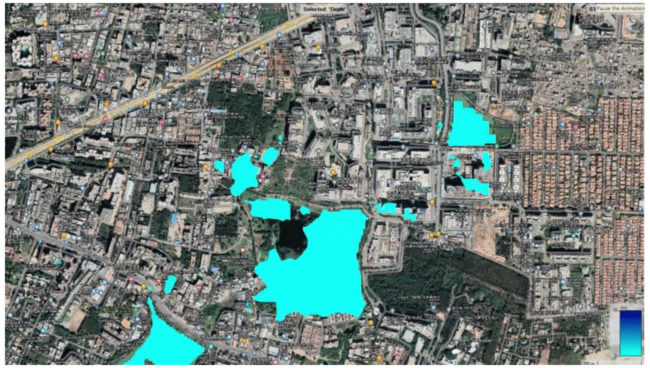
Ward Number : 39

Ward Name : Gandappa Layout & Belmar Layout

73.5 mm

Yelahanka New Town No Rain in this area

Kengeri Satellite Town No Rain in this area



Mujumdar et al., *Current Science* (2021)

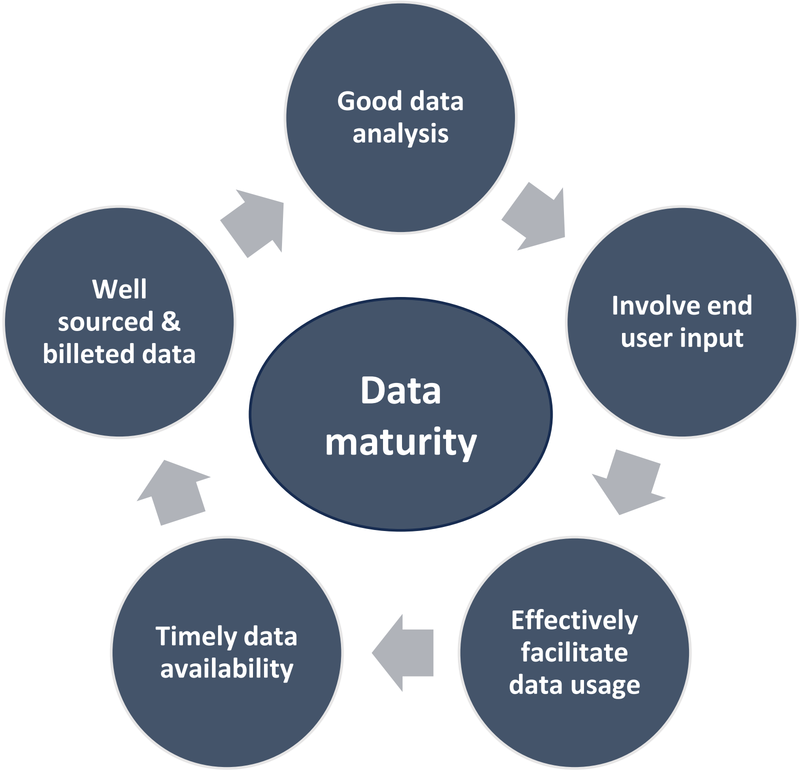
https://varunamitra.karnataka.gov.in/

Key element for implementing digital twins is data maturity

Data maturity using AI/ML approach

Data Maturity

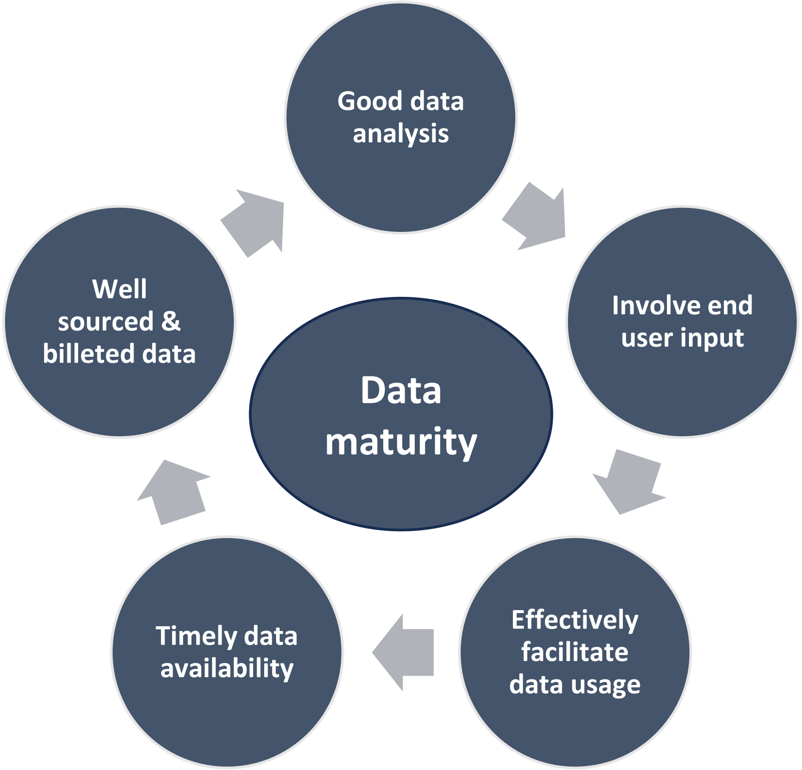
- Uncalibrated models with matured datasets → better performance
- Data maturity – advantage

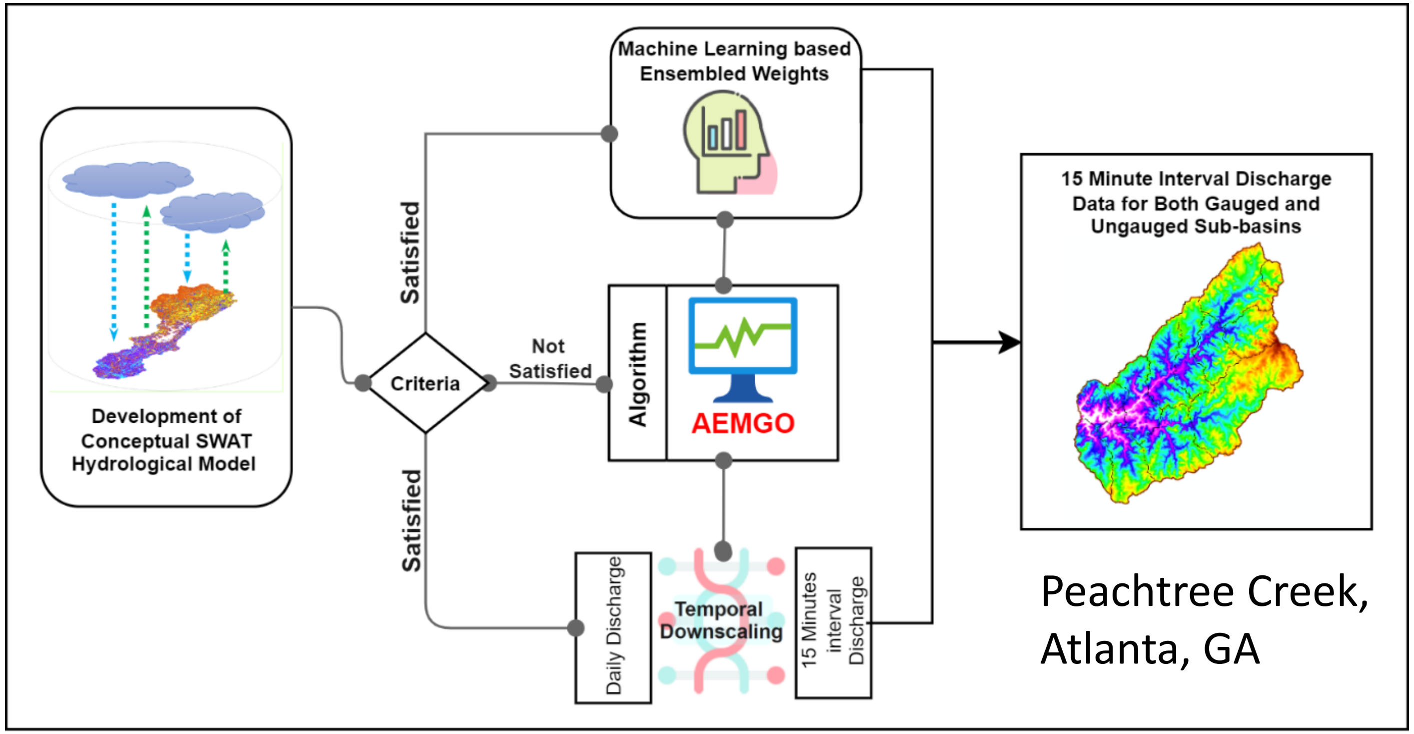


Feeble Data Maturity?

Data Maturity

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





Peachtree Creek, Atlanta, GA

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

V. Bundamala et al., *Journal of Hydrology* (2023)

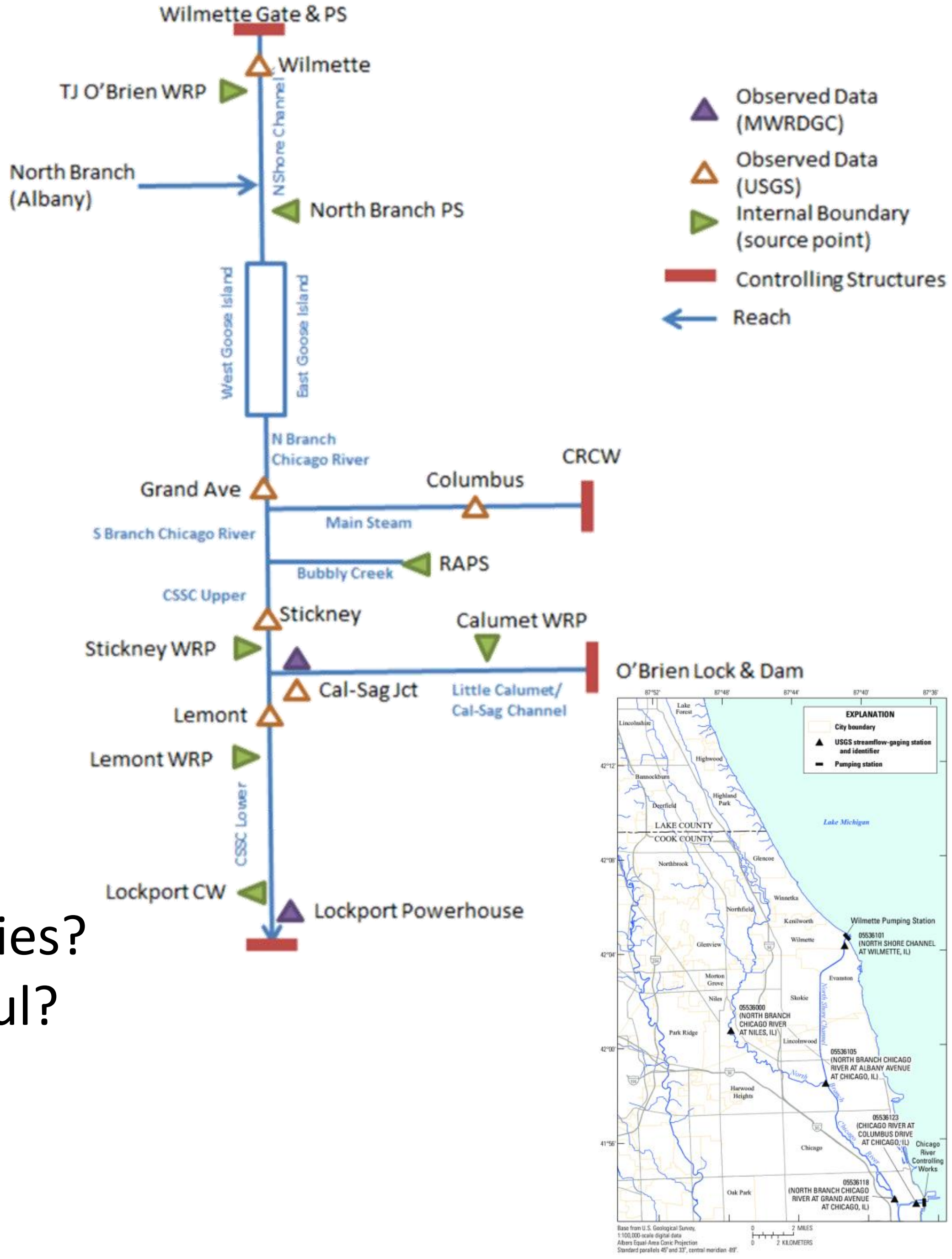
Data Complexities

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?

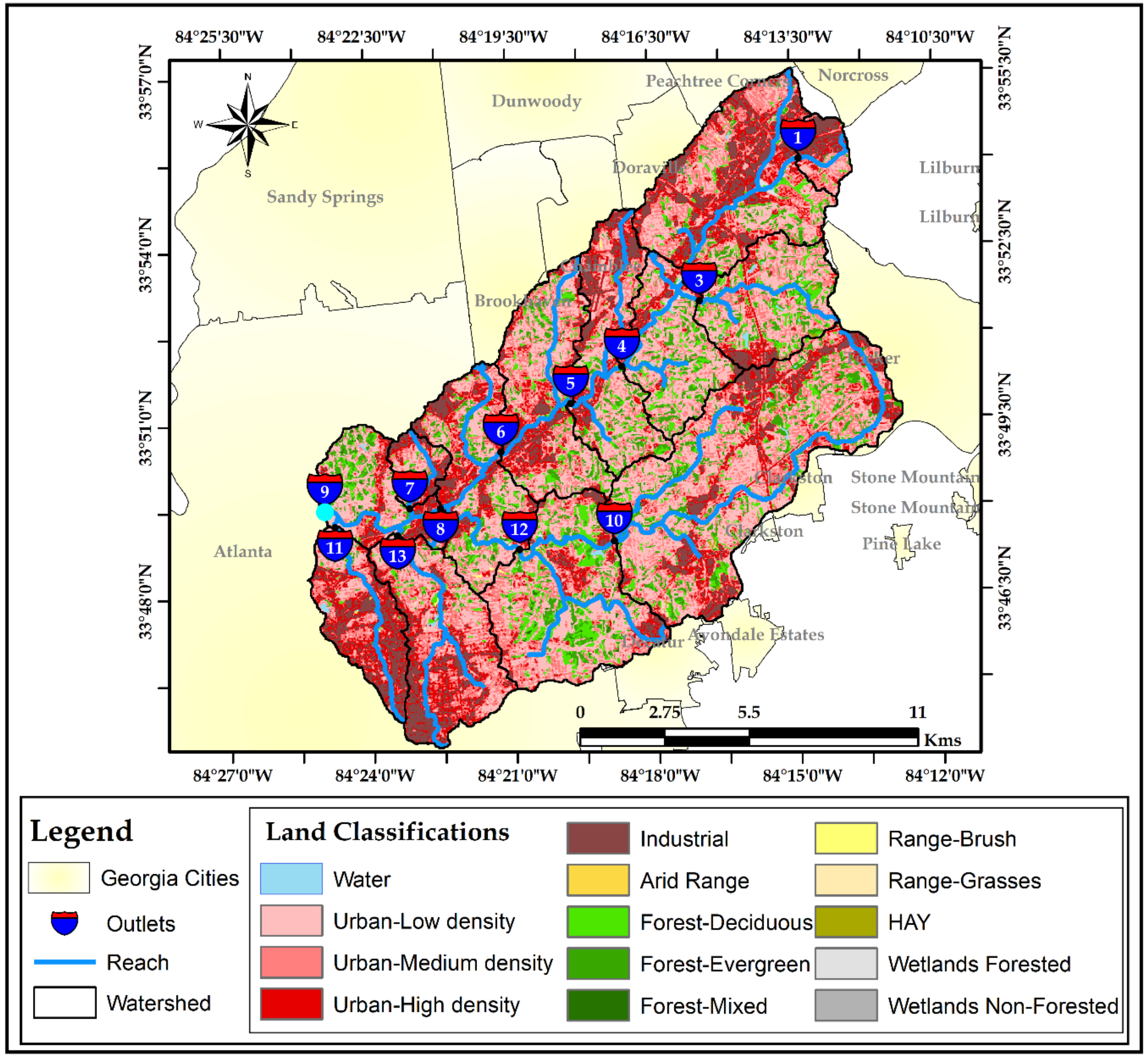


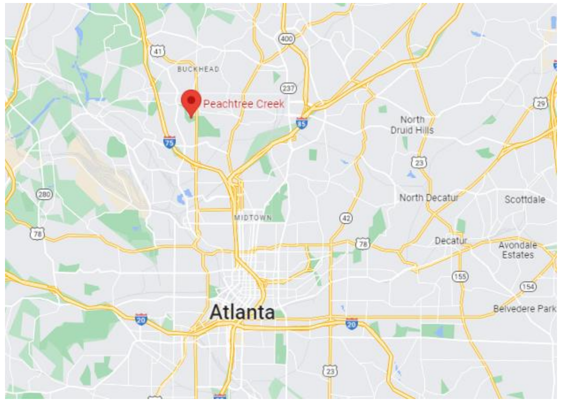
Scientific Investigations Report 2015–5115

An example of Peachtree Creek, Atlanta, GA….

Highlight: Obtain fine resolution data at ungauged stations

Temporal Downscaling



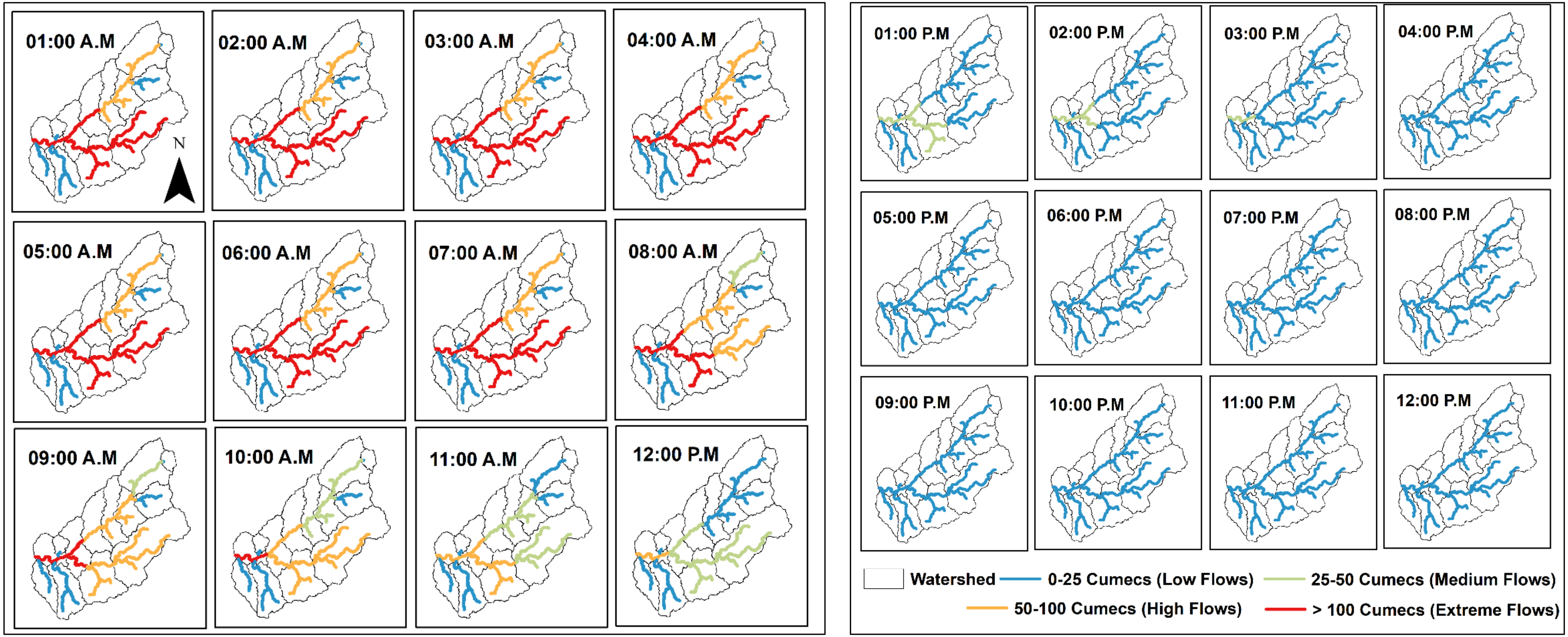


Peachtree Creek,
Atlanta, GA

- 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.

V. Bundamala et al., *Journal of Hydrology* (2023)

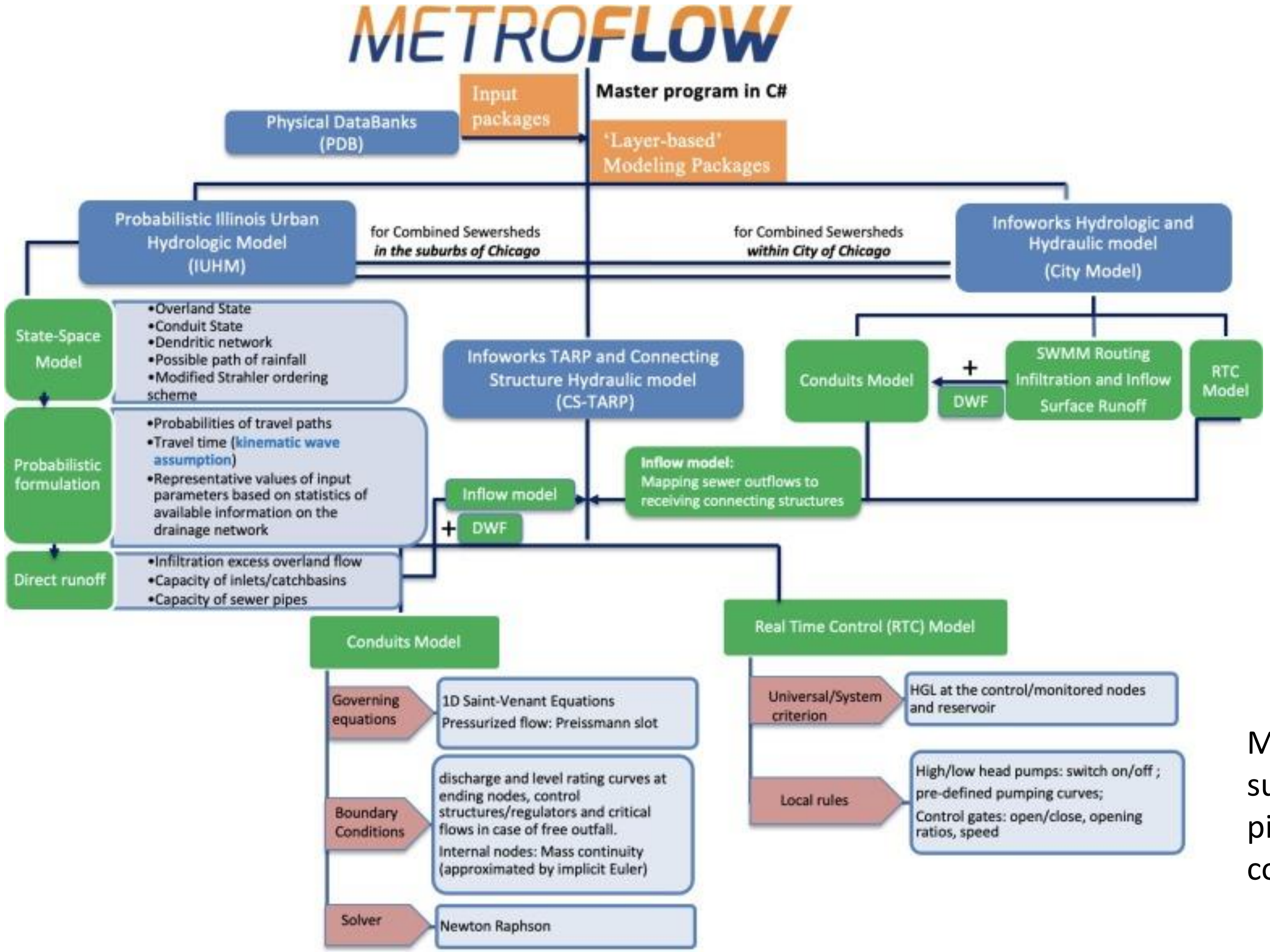
Temporal Downscaling

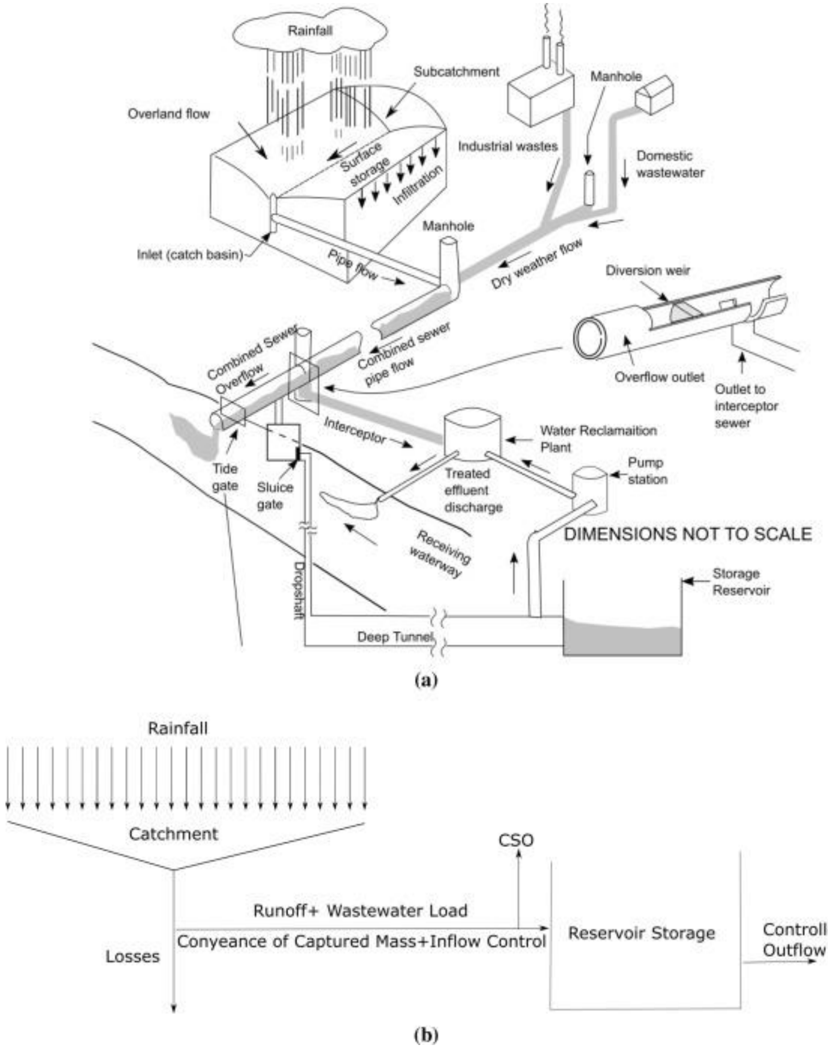


V. Bundamala et al., *Journal of Hydrology* (2023)

Decentralized/Combined Sewer System

Combined Sewer System





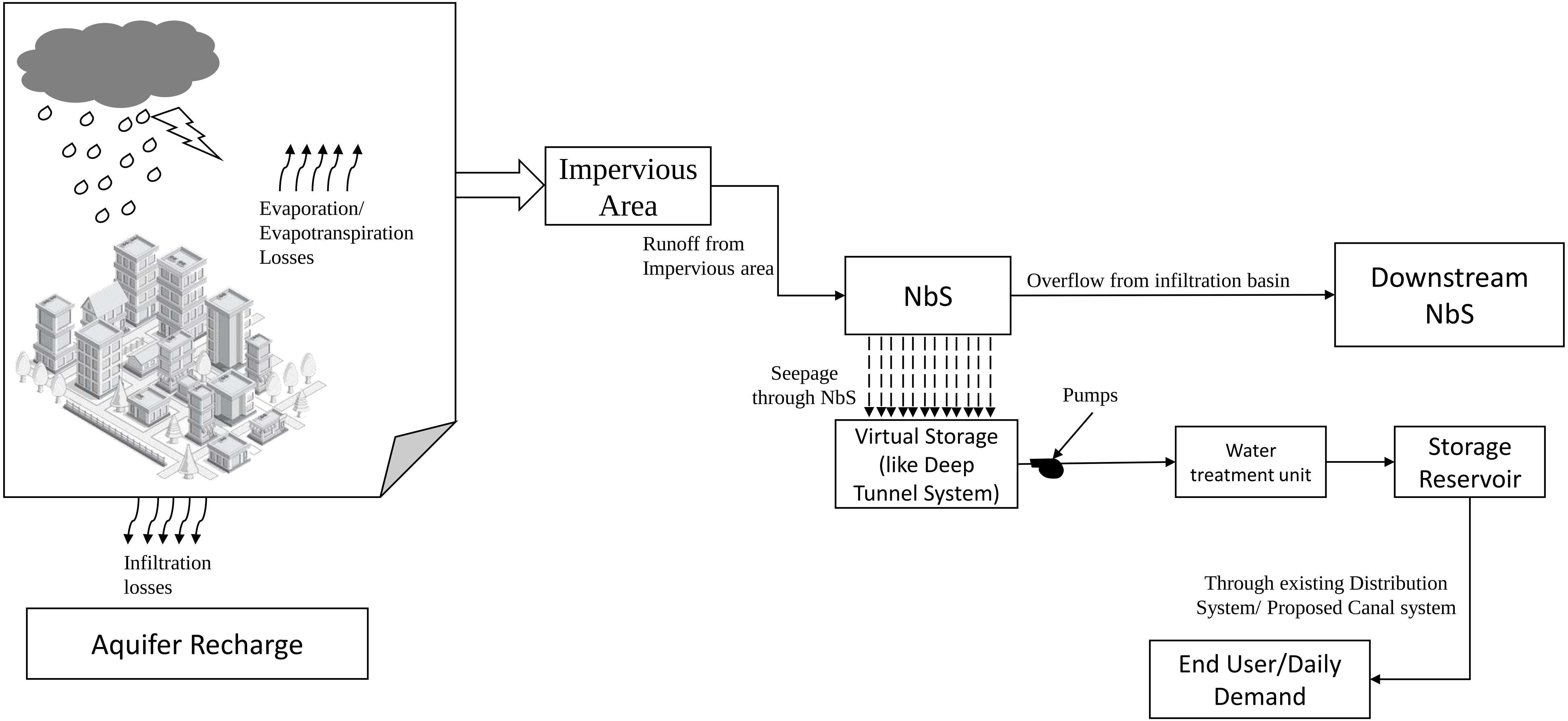
MetroFlow - City's overall urban drainage system: surface and near-surface sewers, interceptors (i.e., the pipes that divert sewage to water reclamation plants), connecting structures and deep tunnel systems.

H. Luo et al., *Journal of Hydrology* (2021)

Decentralized/Combined Sewer System

An example of Vellore, India….

Decentralized Sewer system



Evaporation/
Evapotranspiration
Losses

Infiltration
losses

Aquifer Recharge

Impervious
Area

Runoff from
Impervious area

NbS

Overflow from infiltration basin

Downstream
NbS

Seepage
through NbS

Virtual Storage
(like Deep
Tunnel System)

Pumps

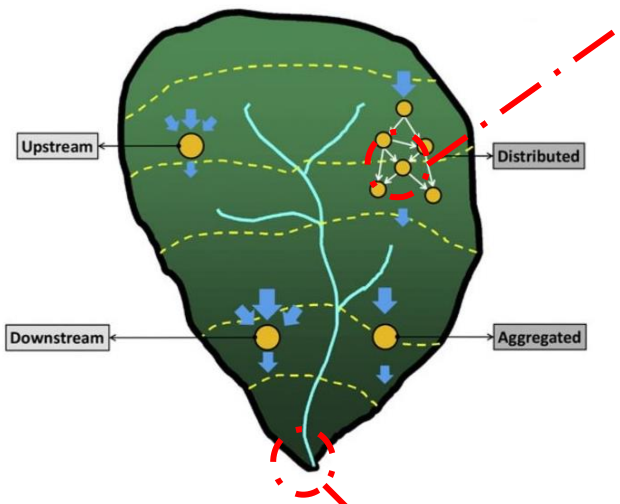
Water
treatment unit

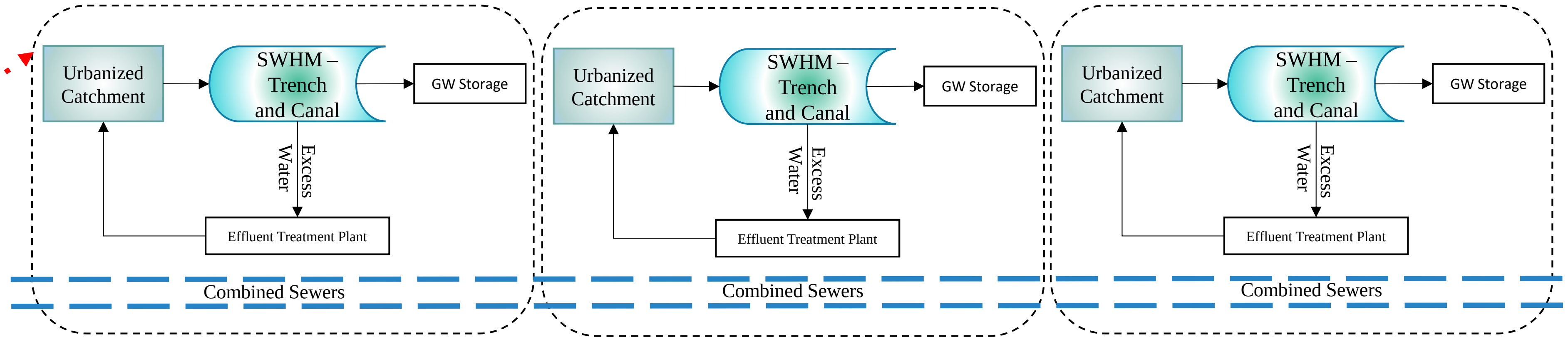
Storage
Reservoir

Through existing Distribution
System/ Proposed Canal system

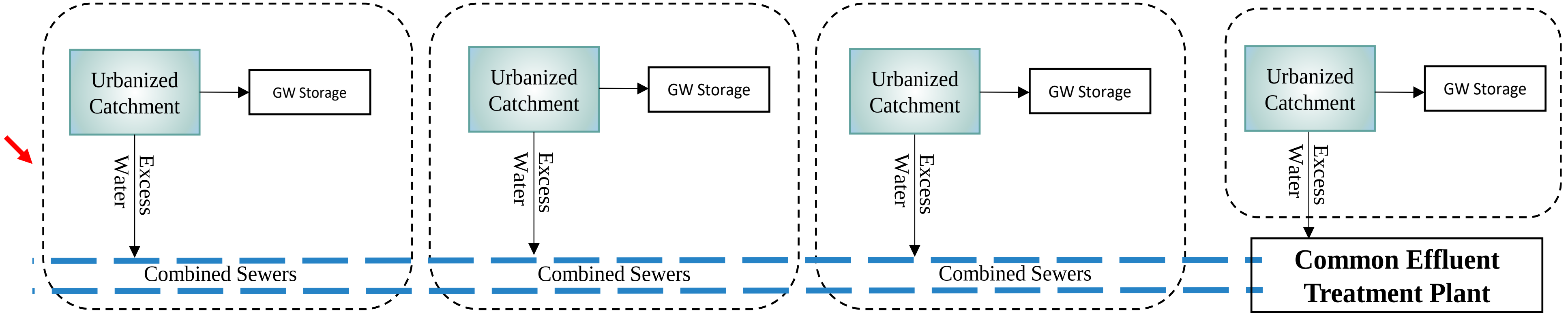
End User/Daily
Demand

Decentralized/Combined Sewer System





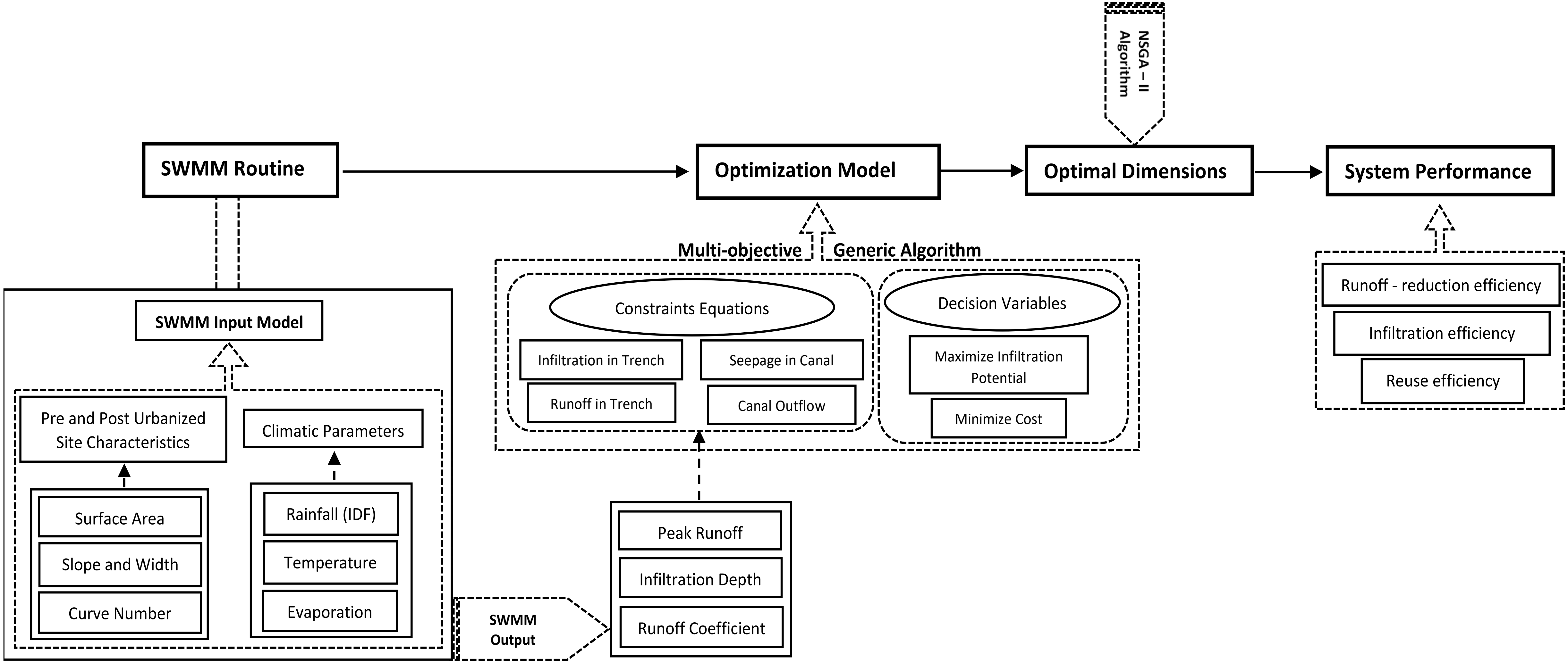
S3/S4 – Decentralized System with Effluent Treatment Plant



S1/S2 - Existing Sewers with Common Effluent Treatment Plant

Wadhwa and Kumar, *AQUA* (2021)

Decentralized/Combined Sewer System



NSGA – II Algorithm

SWMM Routine

Optimization Model

Optimal Dimensions

System Performance

SWMM Input Model

Pre and Post Urbanized Site Characteristics

Surface Area

Slope and Width

Curve Number

Climatic Parameters

Rainfall (IDF)

Temperature

Evaporation

SWMM Output

Peak Runoff

Infiltration Depth

Runoff Coefficient

Multi-objective Generic Algorithm

Constraints Equations

Infiltration in Trench

Seepage in Canal

Runoff in Trench

Canal Outflow

Decision Variables

Maximize Infiltration Potential

Minimize Cost

Runoff - reduction efficiency

Infiltration efficiency

Reuse efficiency

Wadhwa and Kumar, *AQUA* (2021)

Decentralized/Combined Sewer Ssystem

Overall Efficiencies for each Scenario

Design Efficiency (%)	Scenarios			
	S1	**S2**	**S3**	**S4**
$\mathbf{E}_{f_p}$	51	59	65	81
$\mathbf{E}_{\mathbf{rr}}$	39	31	27	-
$\mathbf{E}_{\mathbf{ww}}$	100	18.3	14	-
$\mathbf{E}_{\mathbf{pw}}$	26	31.4	34.2	34.2
$\mathbf{E}_{\mathbf{rmax}}$	39.57	30.86	23.45	58

Efficiencies for Varying Urbanization

Design Efficiency (%)	NbS Scenarios			
	S3	**S4**	**S3**	**S4**
Urban (%)	5.18		56.43	
$\mathbf{E}_{f_p}$	84	82	65	45
$\mathbf{E}_{\mathbf{rr}}$	16	19	39	50
$\mathbf{E}_{\mathbf{rmax}}$	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

Wadhwa and Kumar, *AQUA* (2021)

Nature-based Solutions (NbS) to Mitigate Extremes

NbS to Mitigate Extremes

Critical Facilities

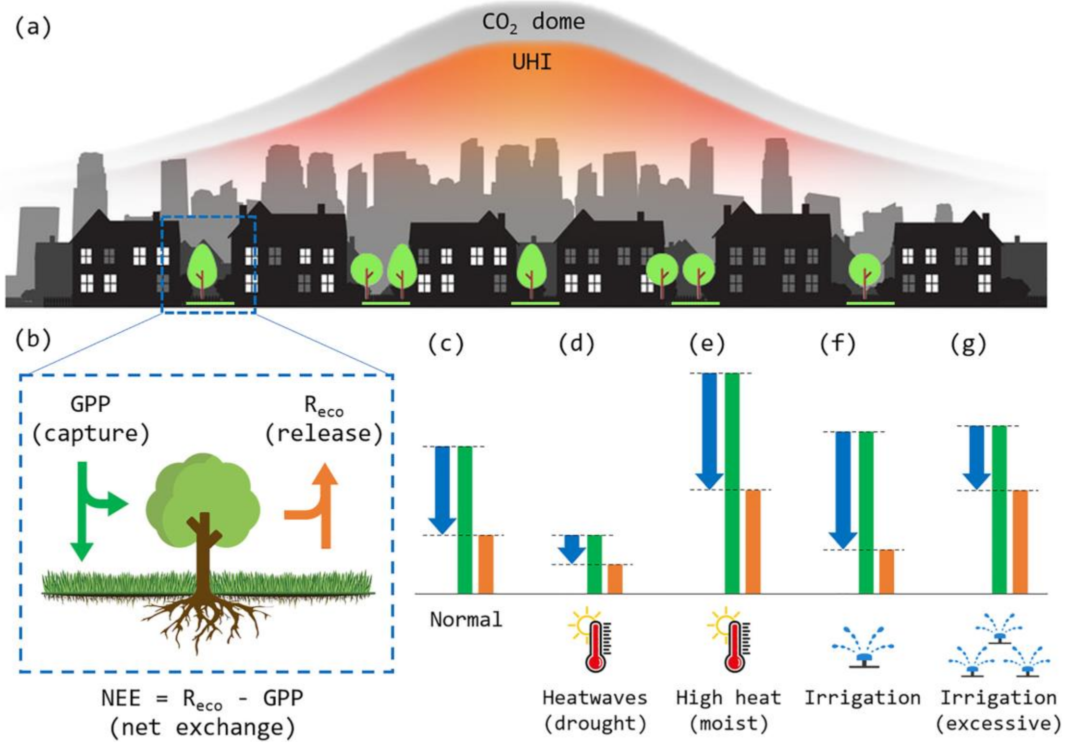
Tourism

Ecosystems and Wildlife

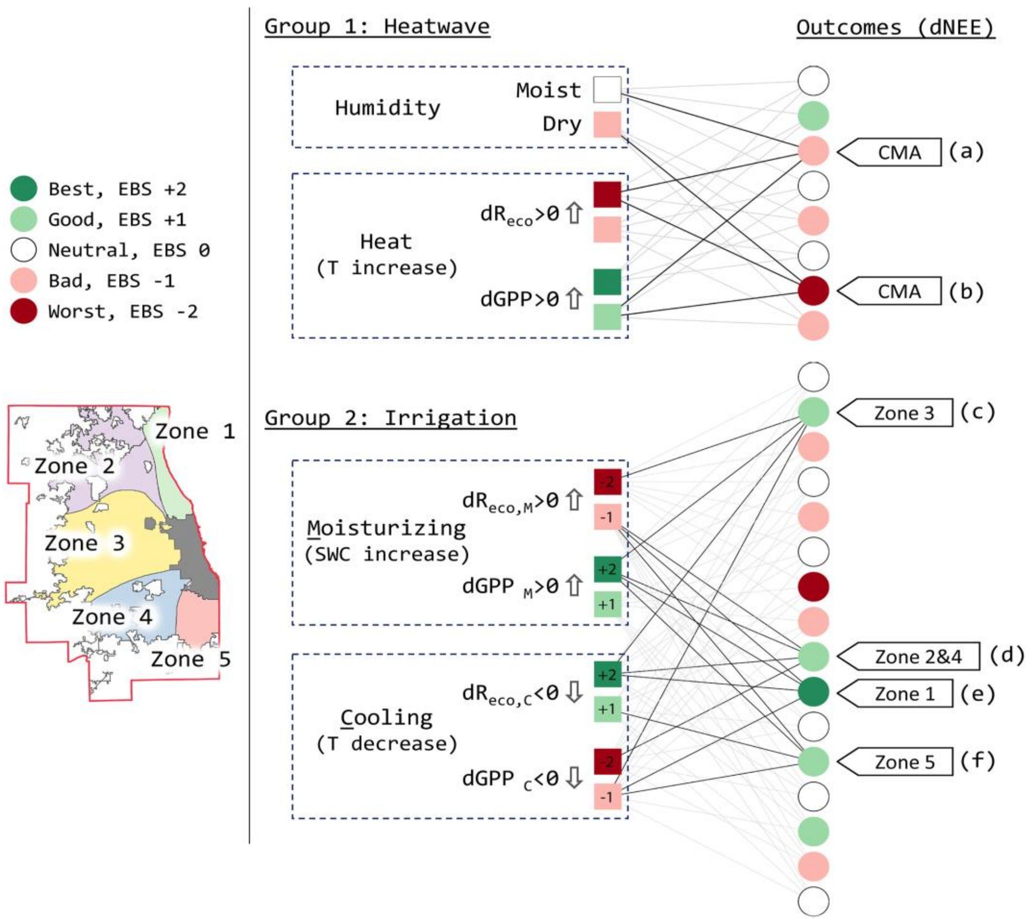

Impact
EIA
Propose alternative
Prevent damage

Projected changes to water quantity and quality

NbS in Carbon Neutrality



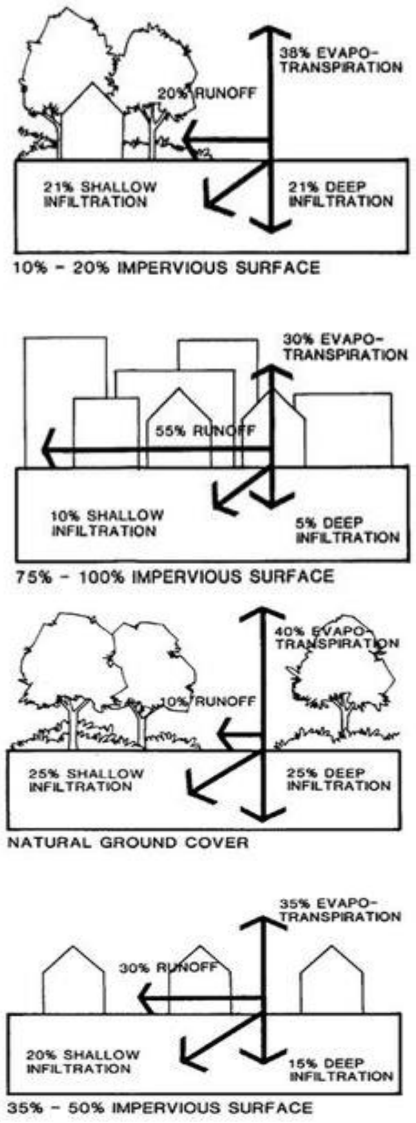
Environmental benefit score

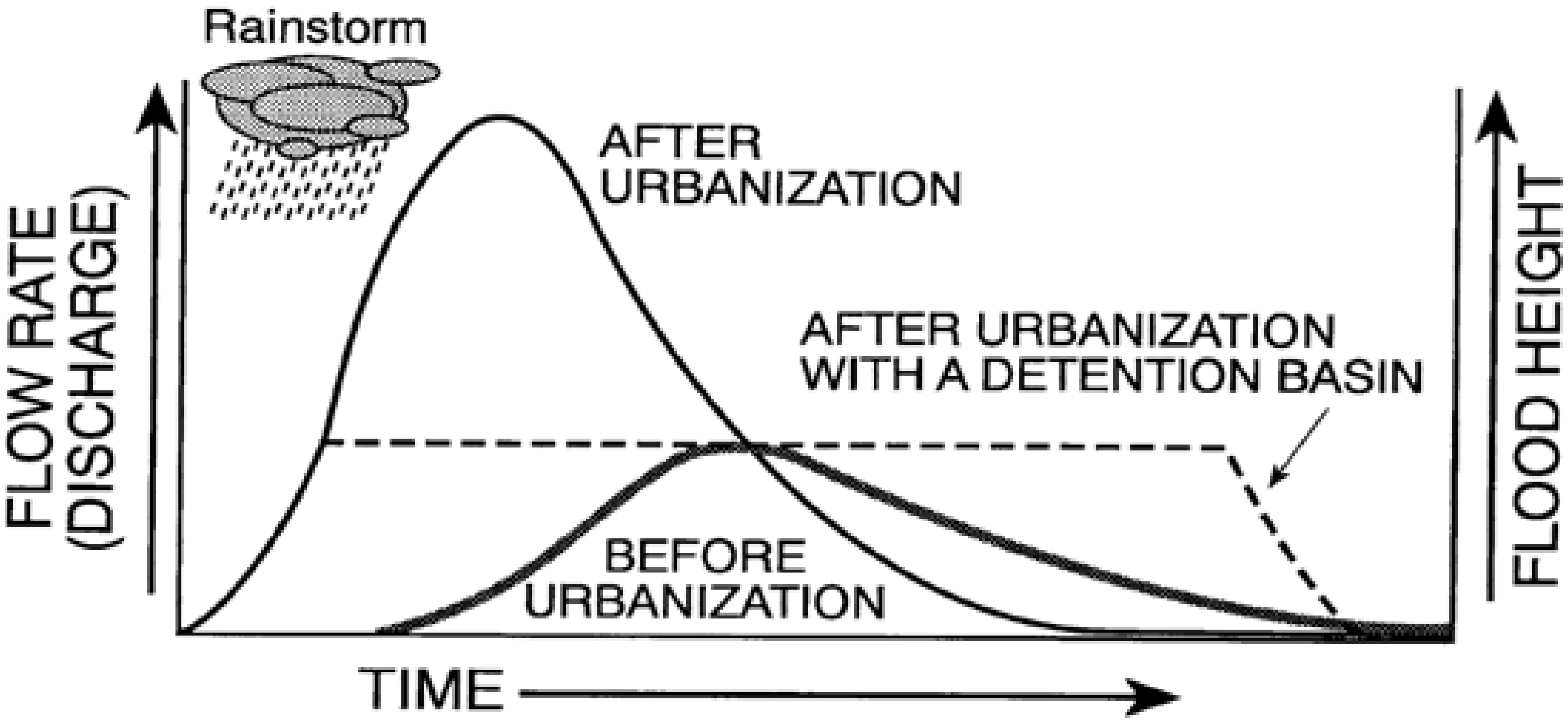


Li et al., *J. Adv. Model. Earth Syst.* (2023)

- 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 CO$_2$ 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

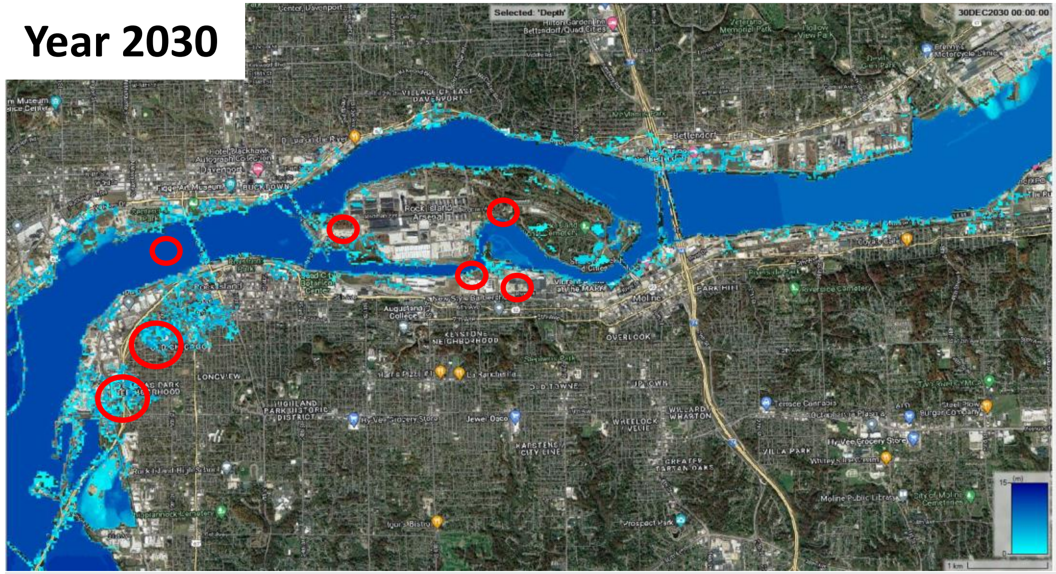
Stormwater Management: A Guide for Floridians

An example….

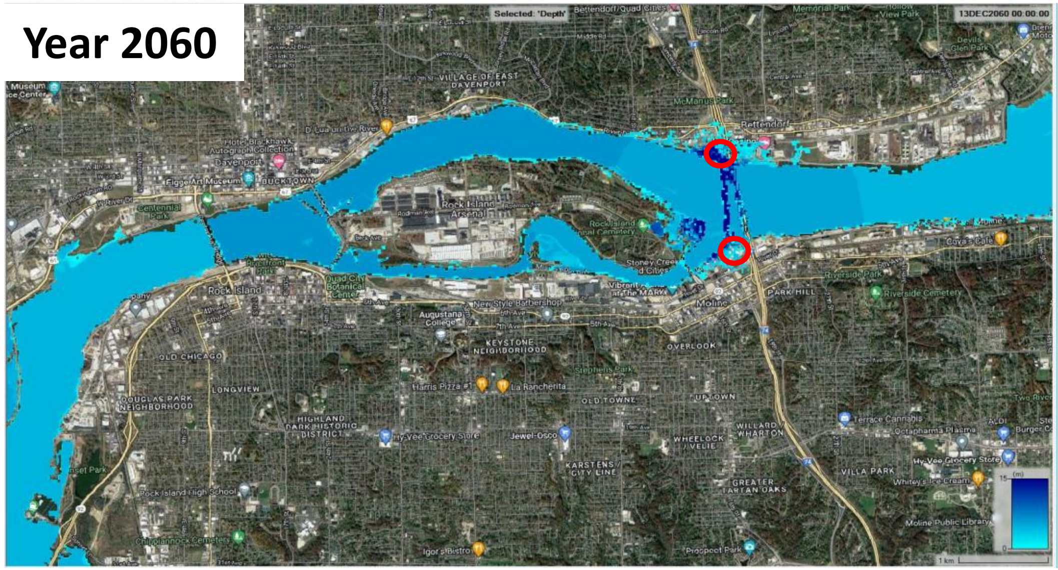
Flood mitigation strategies in QUAD cities using NbS

Flood Inundation Maps for QUAD Cities – Before NbS

Year 2030

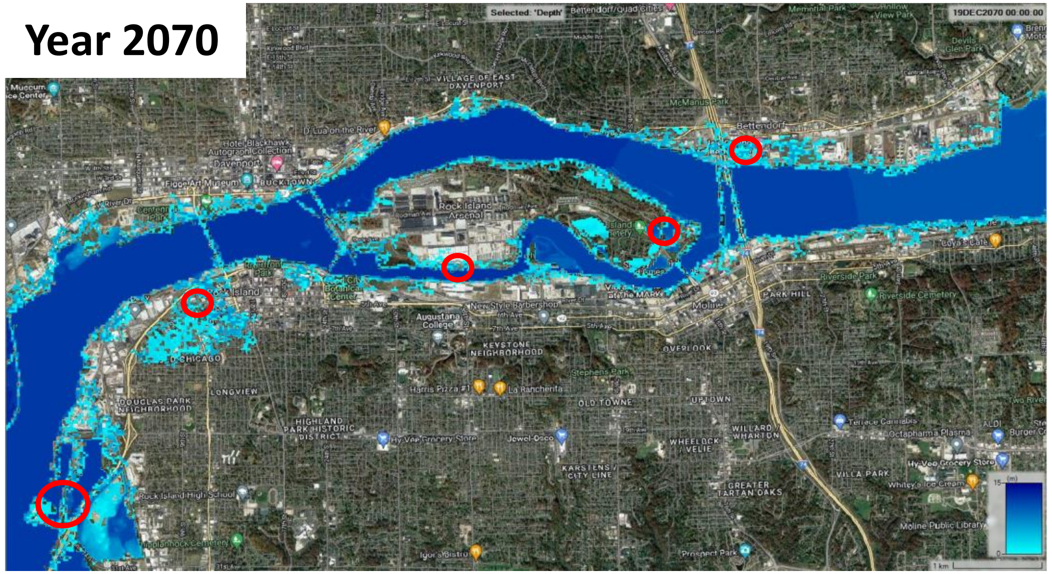


Year 2060

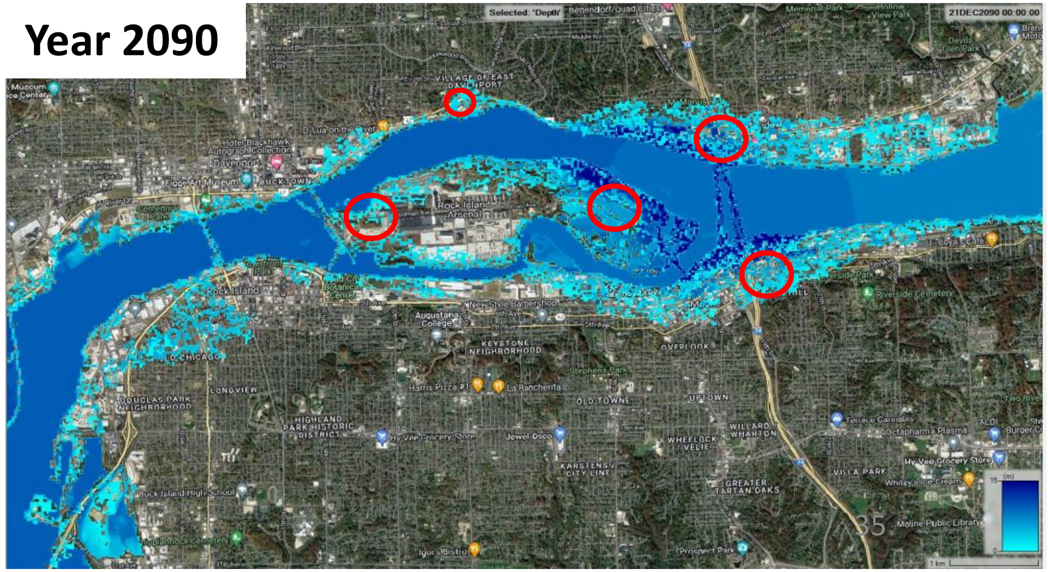


No additional NbS Implemented in QUAD City Region – Operating policy same as historical period

Year 2070

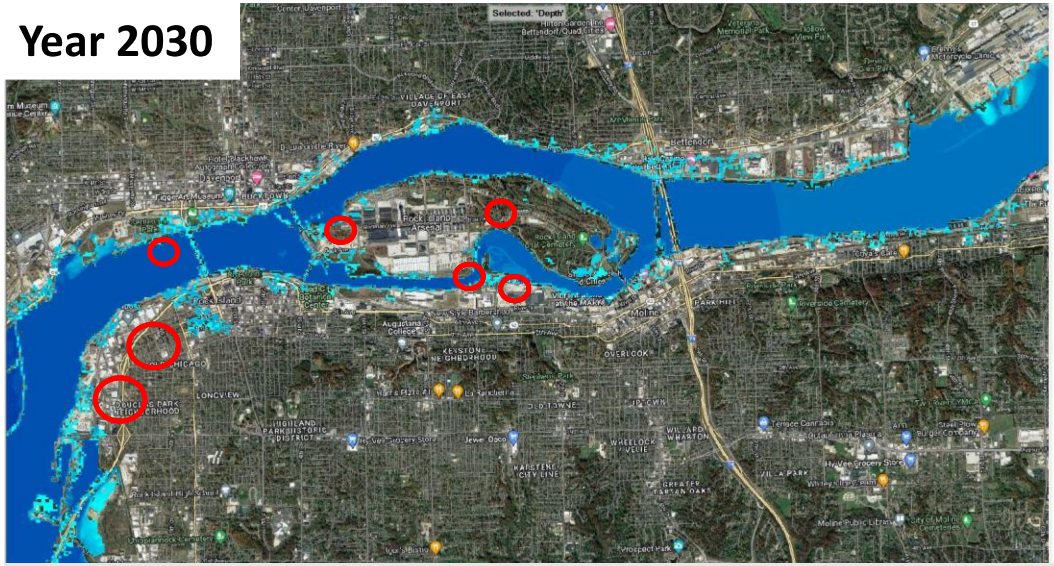


Year 2090

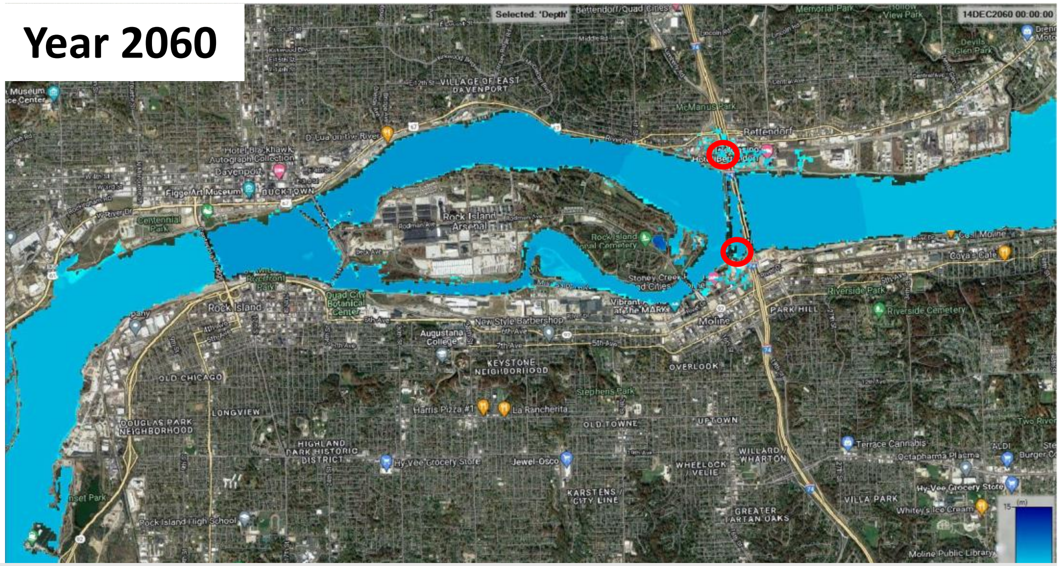


Flood Inundation Maps for QUAD Cities – After NbS

Year 2030

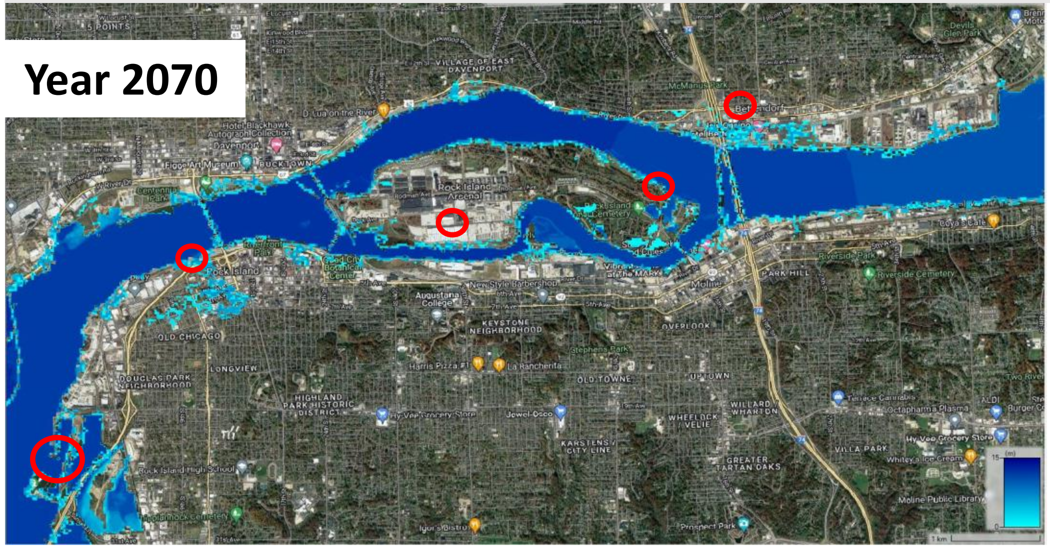


Year 2060

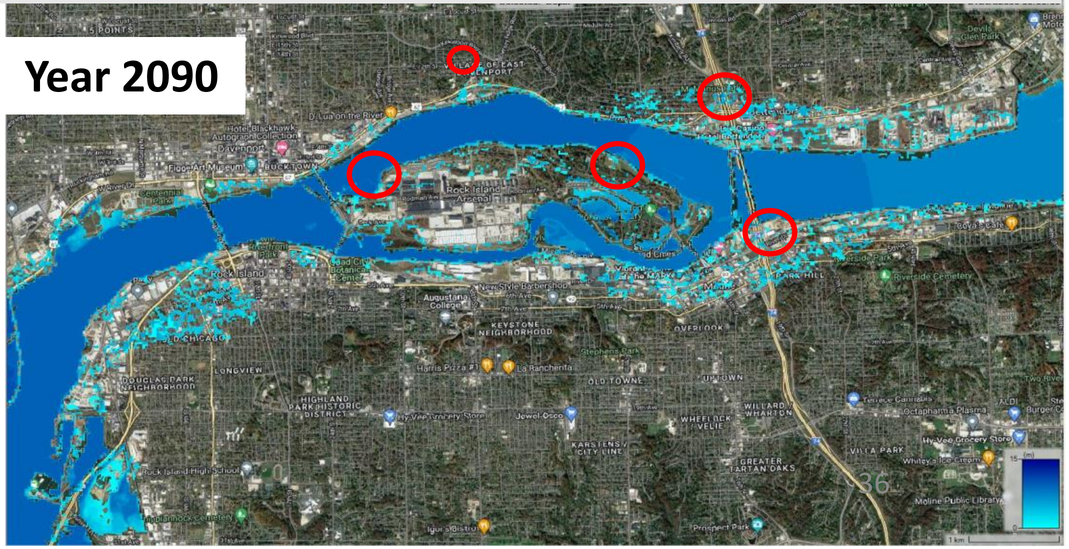


Riparian buffers, Wetlands, Green Roofs - NbS Implemented in QUAD City Region – Operating policy same as historic period

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)

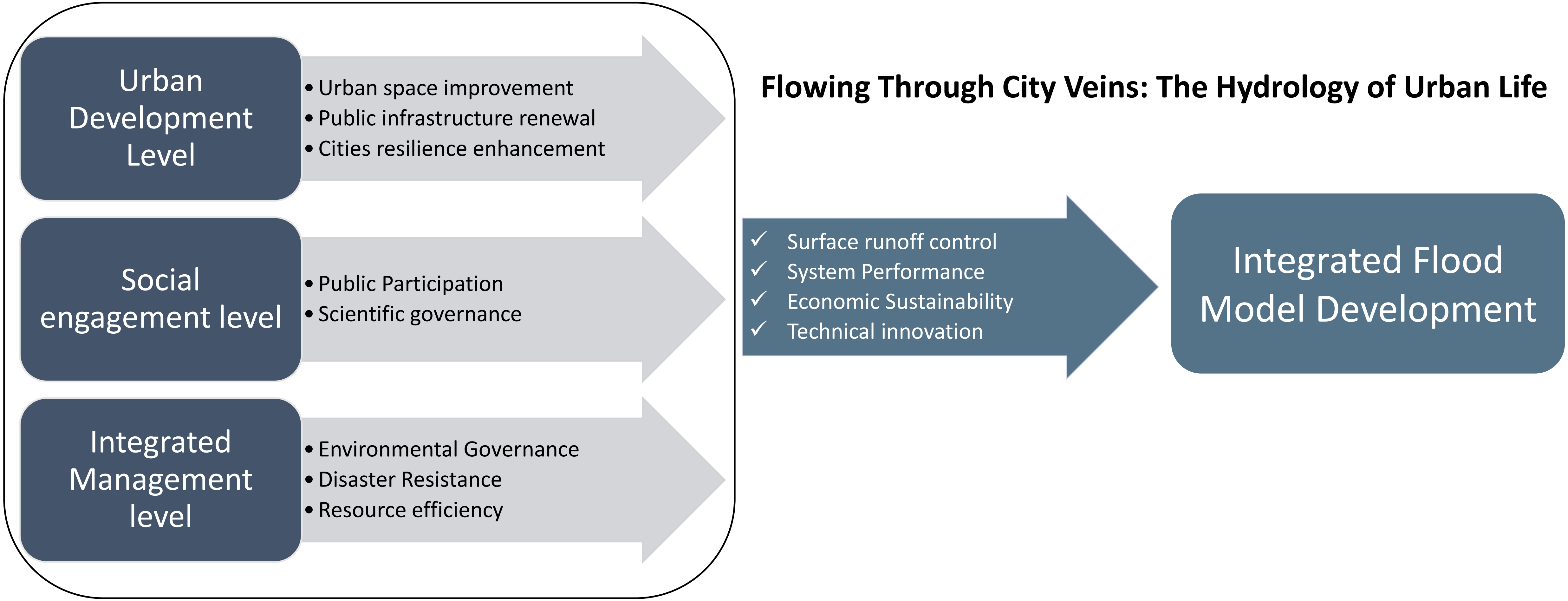
https://www.tandfonline.com/doi/full/10.1080/02626667.2023.2239797

Wadhwa et al.., *Hyd. Sci.* (2024)

Sustainable Flood Risk Management

Sustainable Flood Risk Management

Flowing Through City Veins: The Hydrology of Urban Life



Urban Development Level

- Urban space improvement
- Public infrastructure renewal
- Cities resilience enhancement

Social engagement level

- Public Participation
- Scientific governance

Integrated Management level

- Environmental Governance
- Disaster Resistance
- Resource efficiency

✓ Surface runoff control
✓ System Performance
✓ Economic Sustainability
✓ Technical innovation

Integrated Flood Model Development

Stakeholder Feedbacks

Set the Context

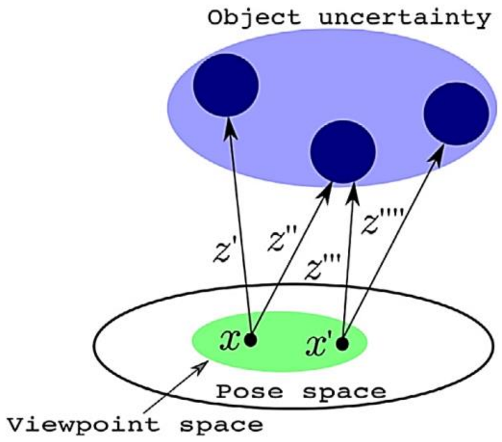
Be Explicit to a Point

Allow, but Track Detailed Design Feedback Separately

Provide General Instructions and Examples

Make Providing Feedback Easy

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

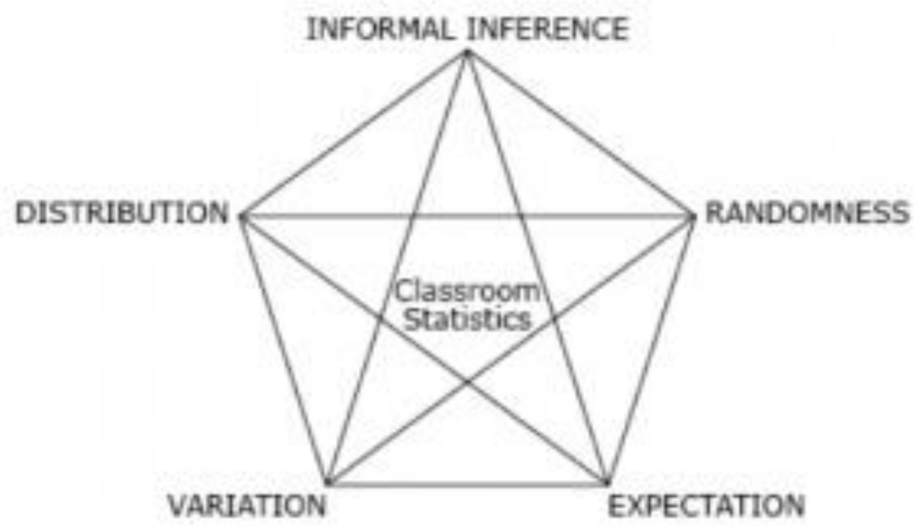
- Literacy
- Income Levels
- Employment Status
- Residential Status

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”

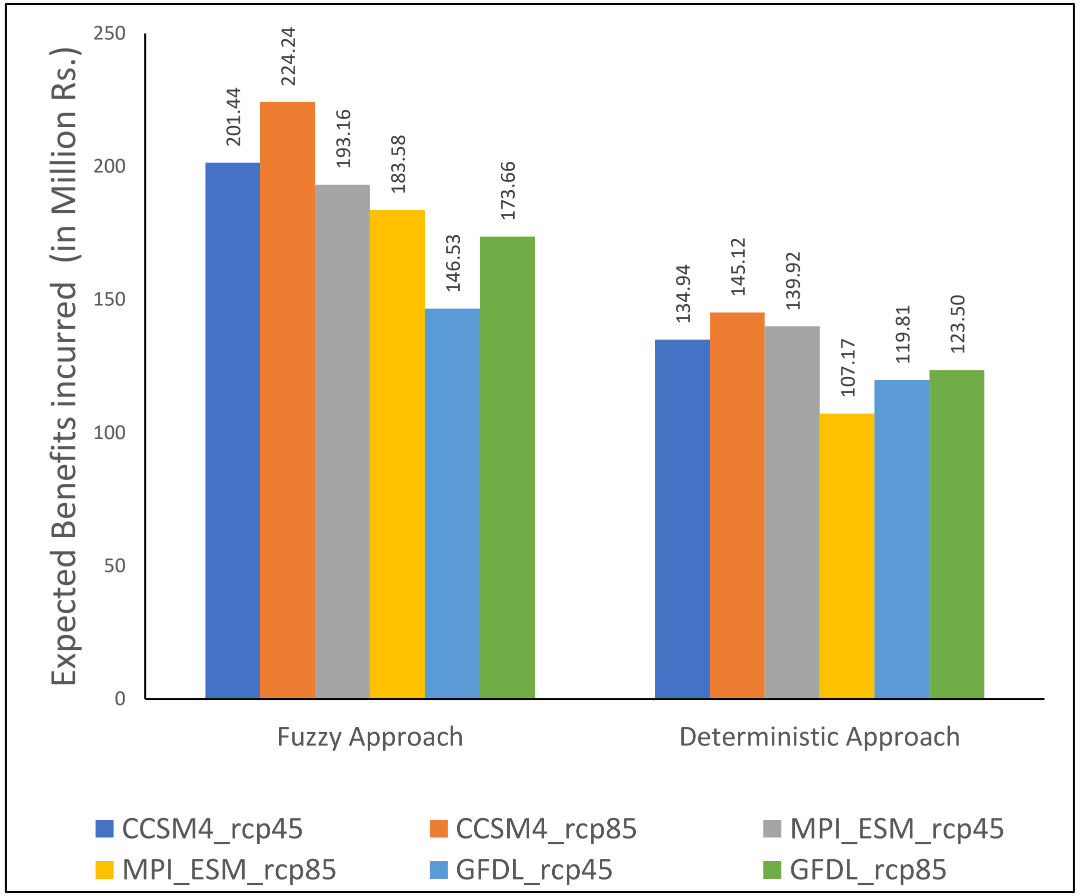
Find benefits obtained from fuzzy approach when compared to deterministic approach

Cost Benefit Analysis

Fuzzy Variable

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

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/m³
C_{M_pond}	Annual maintenance cost for pond	$6\%\ of\ CC_{pond}$	Rs/m³/year
$CC_{conveyance}$	Capital cost of conveyance system	$152.9lby$	Rs/m³
$C_{M\_conveyance}$	Annual maintenance cost of conveyance system	$6\%\ of\ CC_{conveyance}$	Rs/m³/year
$CC_{land\ cost}$	Land acquisition cost for pond	$10324L(B + 2D)$	Rs/m²
$CC_{conv\ land\ cost}$	Land acquisition cost for the conveyance system	$10324lb$	Rs/m²
CC_{SR}	Capital cost of service reservoir	$10324 * \frac{\pi D^2}{4}$	Rs/m³
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/m³
$C_{treatment}$	Annual water treatment cost	$0.0063(T_{inflow} - T_{outflow})$	Rs/m³
PWF	Present worth factor	$\frac{r(1+r)^t}{(r+1)^t - 1}$	
$C_{w,i}$	Benefit obtained to supply water/lpcd		Rs



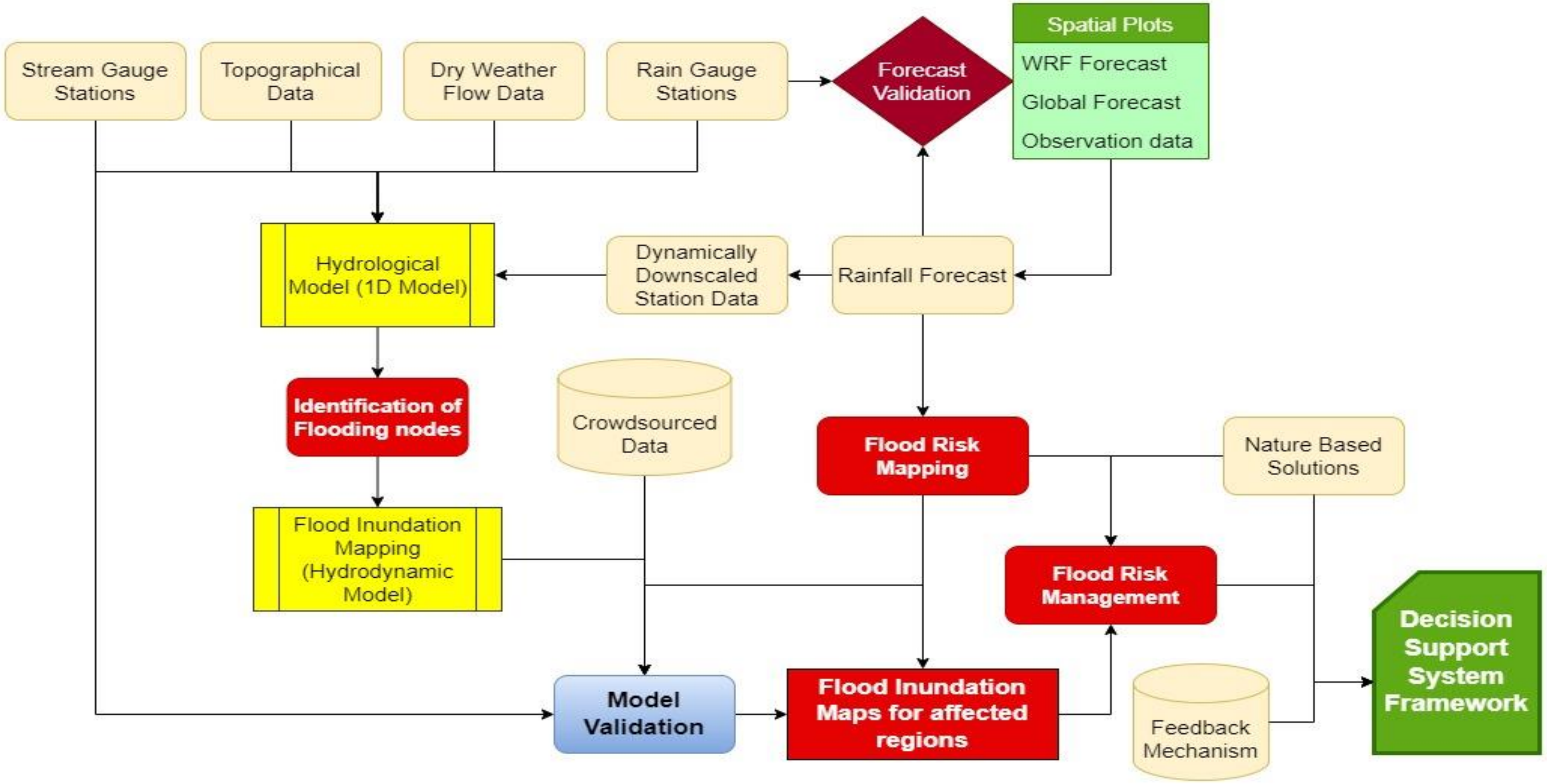
Vision for Urban Cities

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.



Stream Gauge Stations

Topographical Data

Dry Weather Flow Data

Rain Gauge Stations

Forecast Validation

Spatial Plots

WRF Forecast

Global Forecast

Observation data

Hydrological Model (1D Model)

Dynamically Downscaled Station Data

Rainfall Forecast

Identification of Flooding nodes

Crowdsourced Data

Flood Risk Mapping

Nature Based Solutions

Flood Inundation Mapping (Hydrodynamic Model)

Flood Risk Management

Decision Support System Framework

Model Validation

Flood Inundation Maps for affected regions

Feedback Mechanism

Thank you