Food-water-energy for Urban Sustainable Environments in Pune, India

@Team1Fuse

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Who are we?

FUSE

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Sponsors

BELMONT FORUM

Sustainable Urbanisation Global Initiative (SUGI)

FOOD-WATER-ENERGY NEXUS

Partner Organizations | **Funding Organization**

United States

STANFORD UNIVERSITY

NSF

Austria

IIASA International Institute for Applied Systems Analysis

ÖFSE Austrian Foundation for Development Research

FFG Austrian Research Promotion Agency

Germany

UFZ HELMHOLTZ Centre for Environmental Research

Federal Ministry of Education and Research

Local Partners & Stakeholders

Water Resources Department (WRD) Maharashtra

ACWADAM

CEE Centre for Environment Education

Education : An Ennobling Influence

Gopal Krishna Gokhale

Gokhale Institute of Politics and Economics (Deemed to be University)

MIRRA METHODS FOR IRRIGATION AND AGRICULTURE

+ Many Others

The FUSE Team

Stanford, US
Hydro, Food, Agent Model


Steve


Roz


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Ju Young


Hassaan

IIASA, Austria
Hydro, Agro, Climate


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Yuanzao

ÖFSE, Vienna, Austria
SLLs, Stakeholder Engagement


Karin


Ines

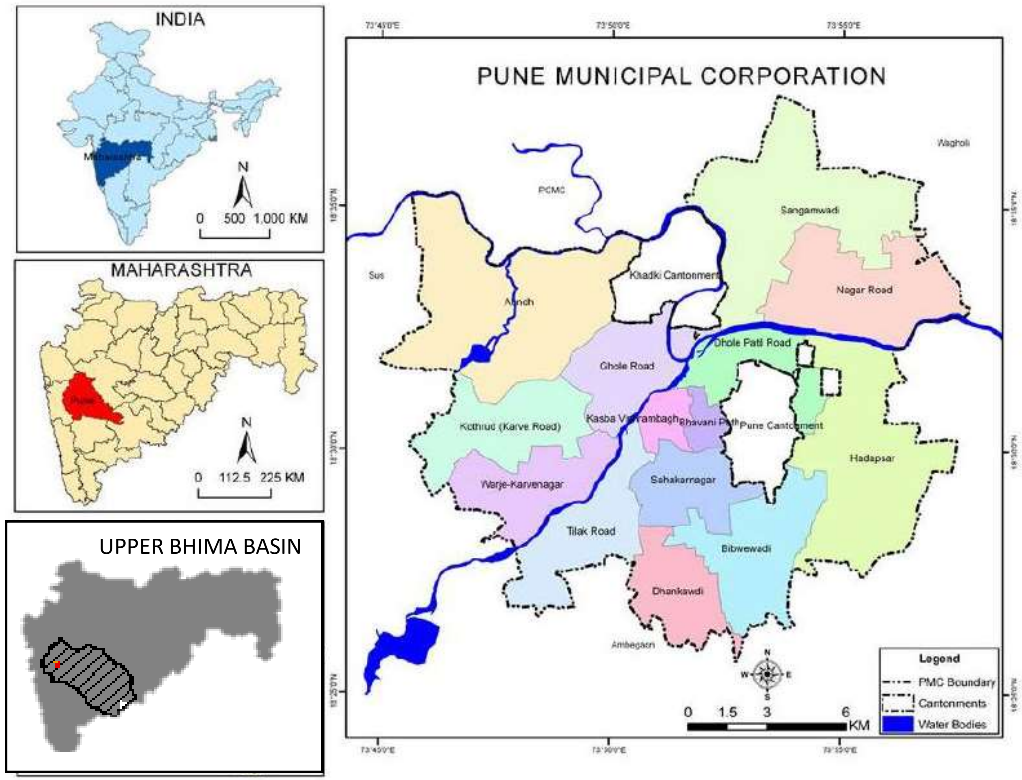

Hannes

In India during Jan 2020

Project Goals

Produce solutions for urban-FWE challenges through participatory model building

Study Areas

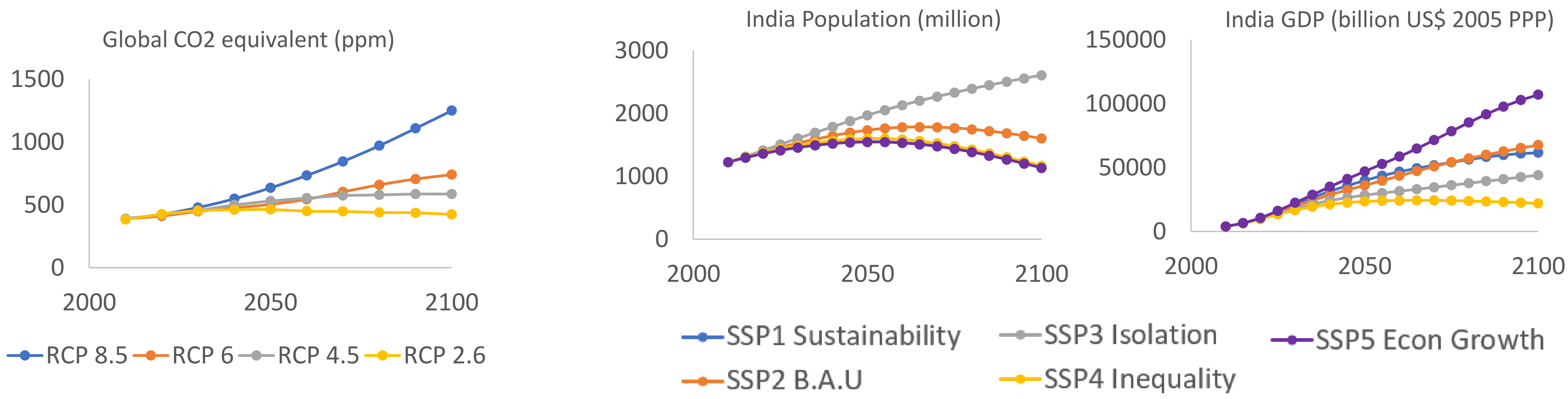


Pune, India

FEW Drivers: Urbanization and Climate Change

Based on Assumptions of Representative Concentration Pathways (RCP) for greenhouse gases and Shared Socio-economic Pathways (SSP) for economic growth

Scenario matrix = RCP x SSP



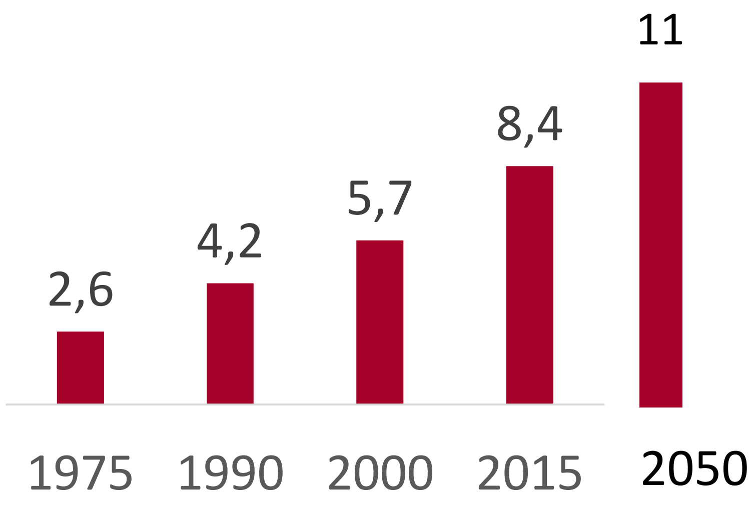
Downscaled To Local Scale

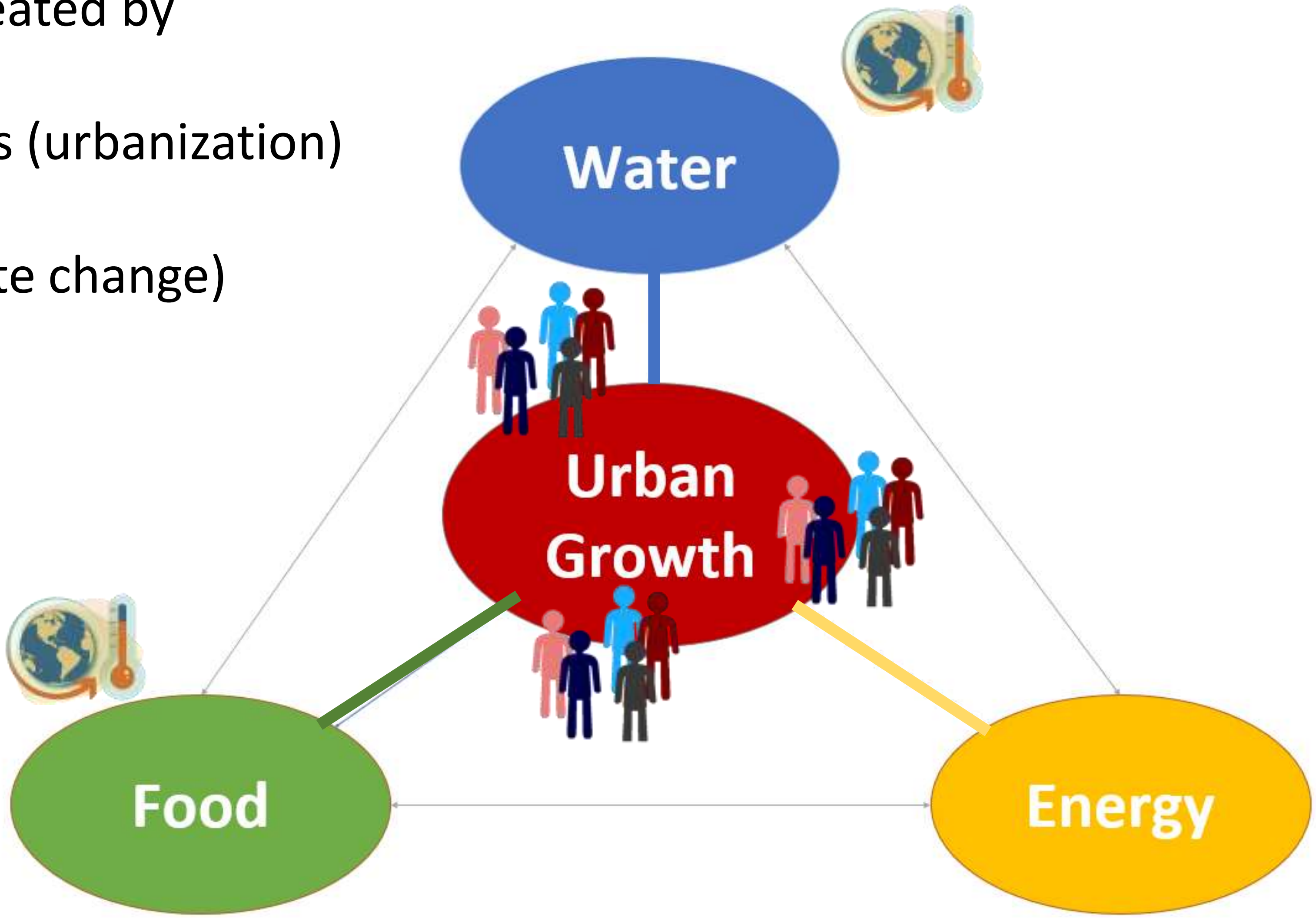
Nexus Drivers: Urbanization and Climate Change

<u>Nexus Challenges:</u> Vulnerabilities created by

- Increasing population demands (urbanization)
- Changing resource base (climate change)

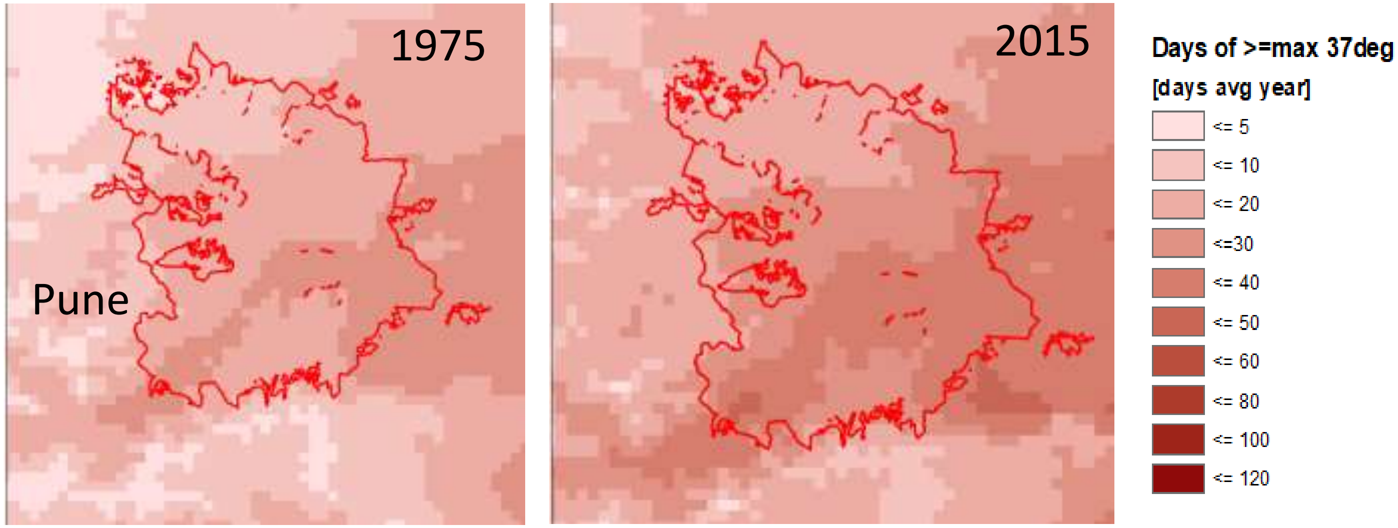
Pune Metro population (millions):



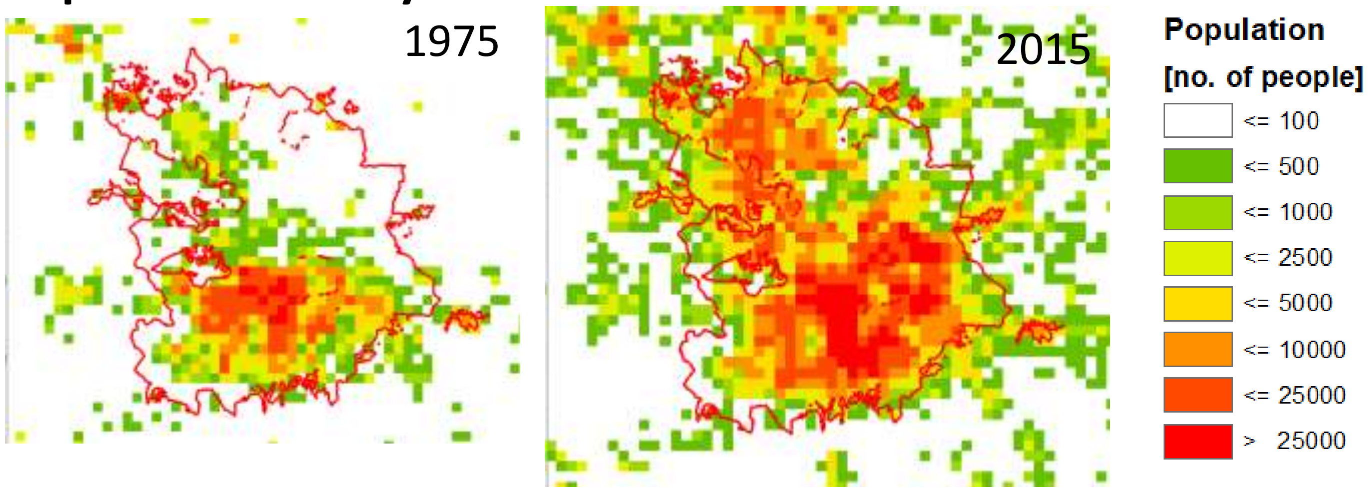


Pune Nexus Challenge Example: Urbanization x Temperature

Days Temperature Exceeds 37 C



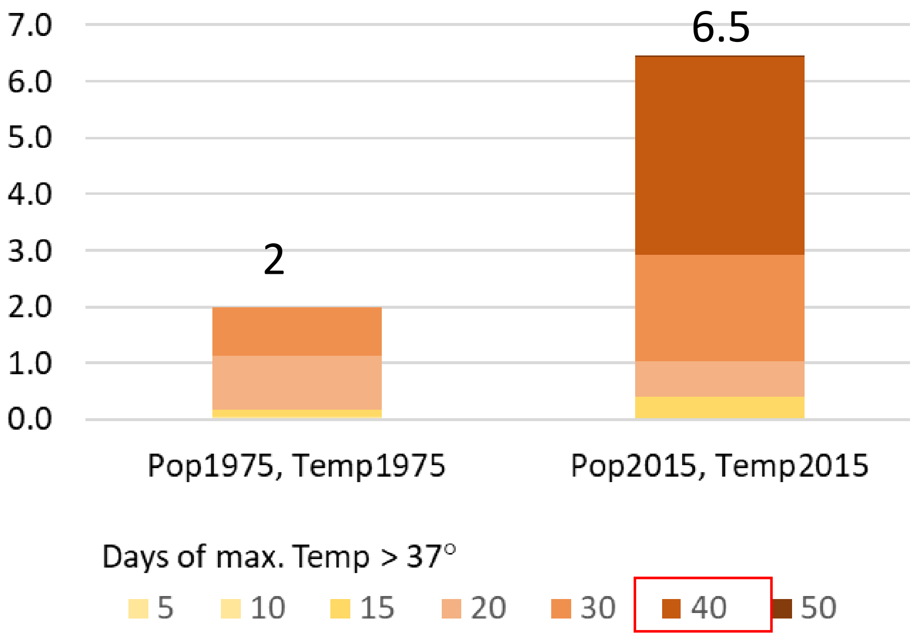
Population density



Data: GHSL

Vulnerability Metric:

Number of people (millions) experiencing max temp >37 C for X number of days.

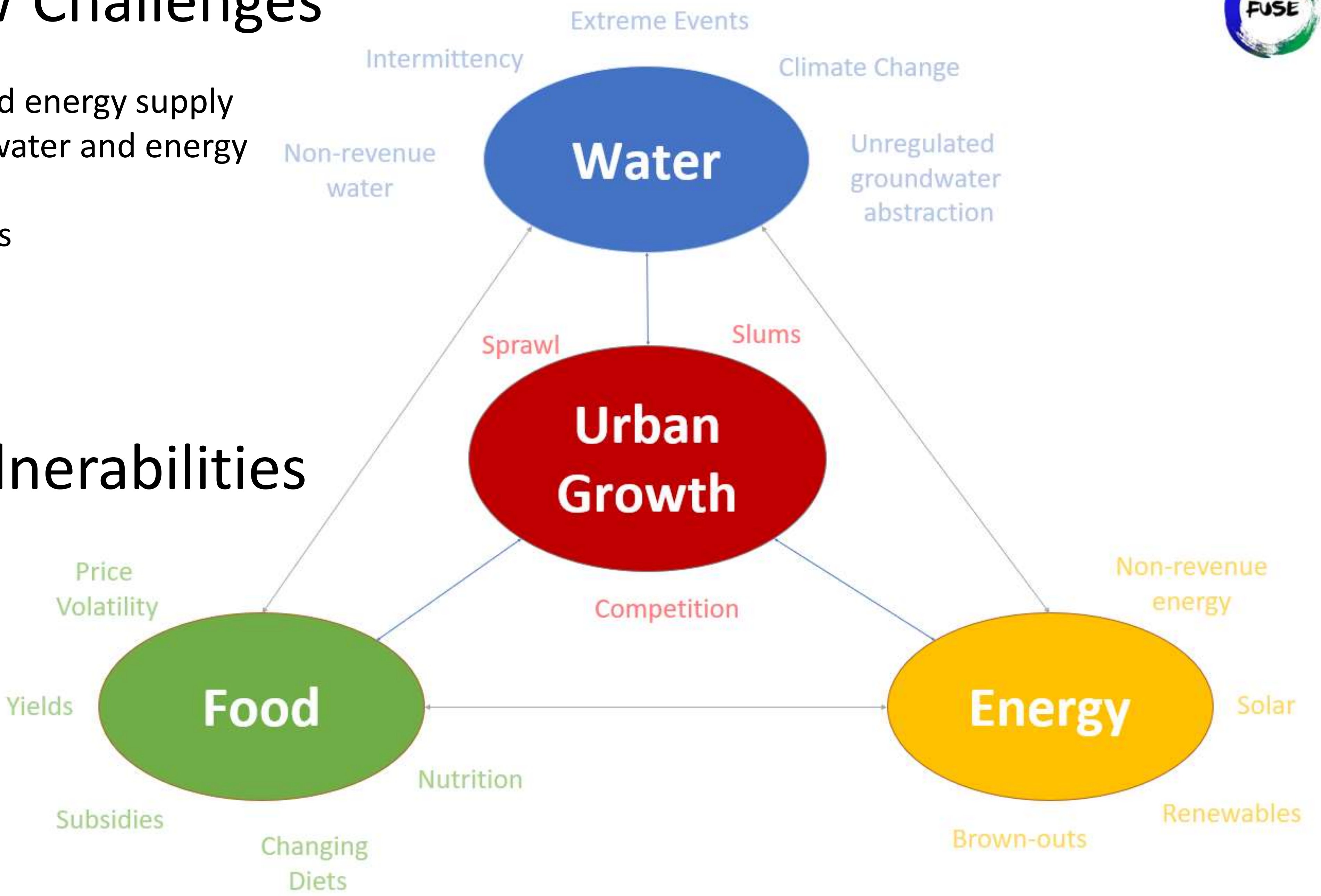


Changing the frequency and impact of heat waves has implications for cooling (energy, water) and crops (food)

Identifying FEW Challenges

- Intermittency of water and energy supply
- Sectoral competition for water and energy
- Climate-change impacts
- Political economy histories
- Governance systems
- Infrastructure decay

Quantifying Vulnerabilities



Co-Creation Approach - FUSE Process Steps:

1

- Get stakeholder ideas about future challenges
- Experts add ideas and propose solutions

2

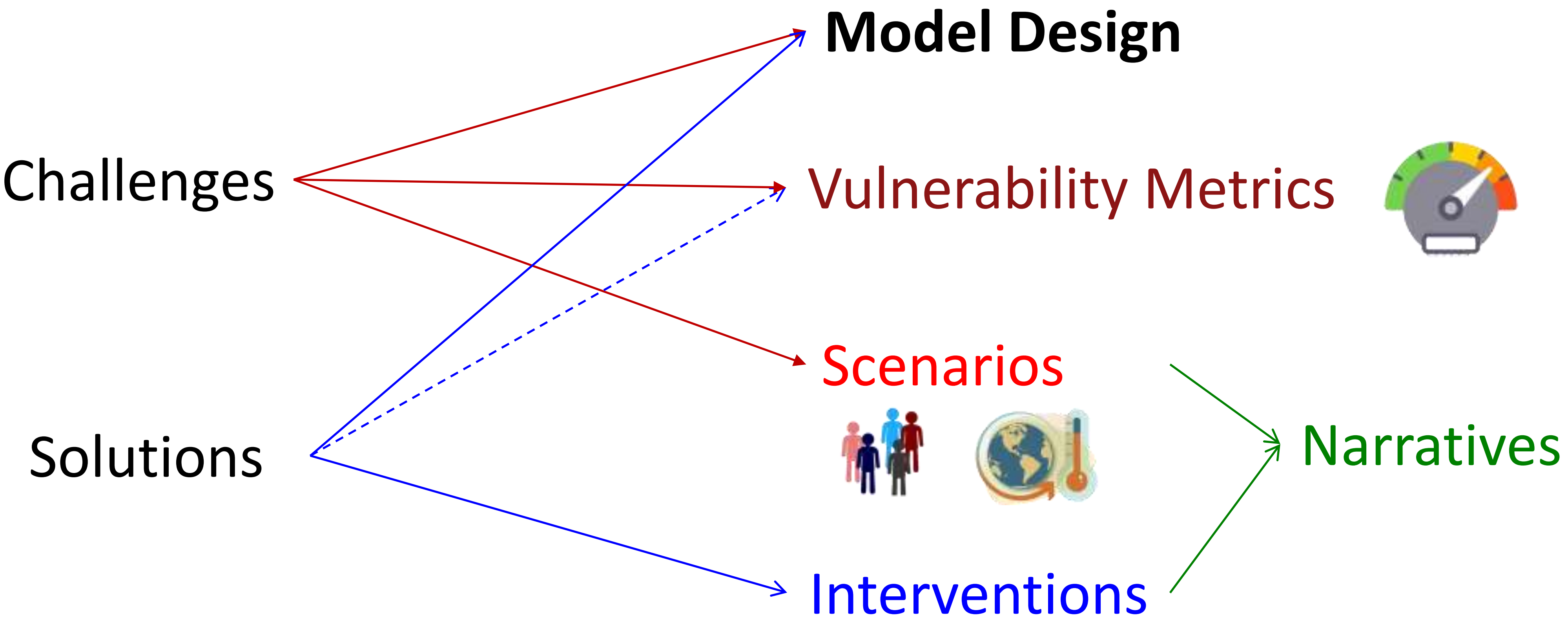
- **FUSE team develops a policy-evaluation model incorporating all ideas**

3

- Get stakeholder responses to policy-evaluation results

Narrative Development Process

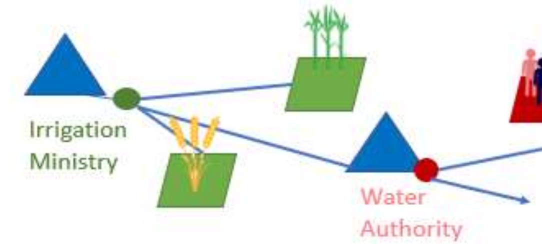
Sustainability Living Labs (SLL) Co-Creation Process



Conceptualizing the Nexus Model

Agent Network Module

Tests policy decisions by institutions and managers to supply resources



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Agriculture Module

Determines the crop type, crop area extent, and water quantity demanded by crop and source

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Urban Module

Determines urban extent, population density, and urban resources demands

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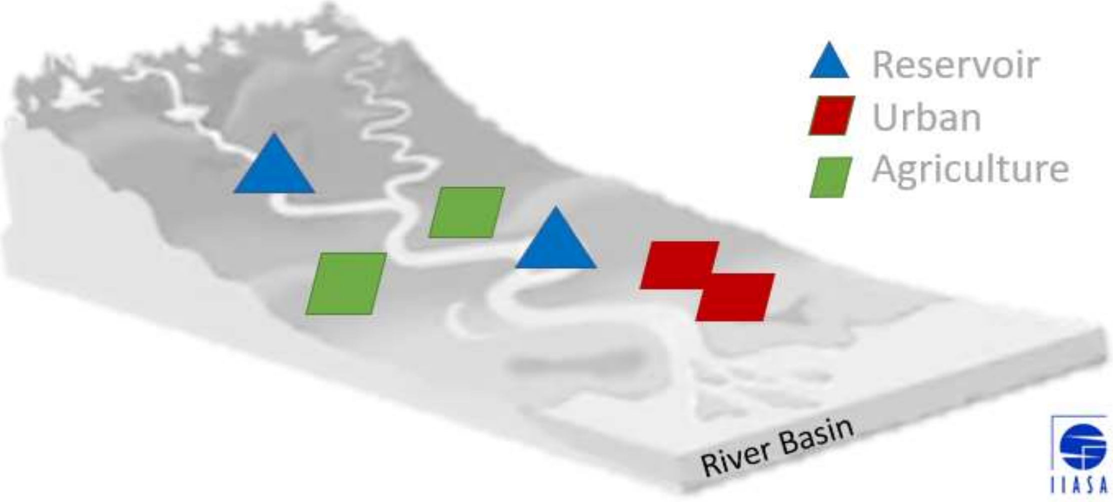
Water Module

Uses climate forcing to calculate available water based on land-use



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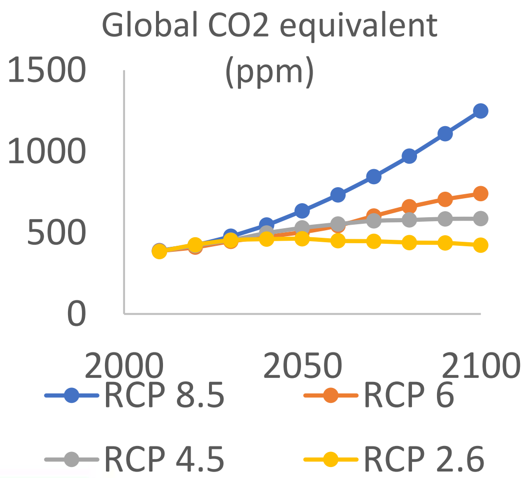
Climate

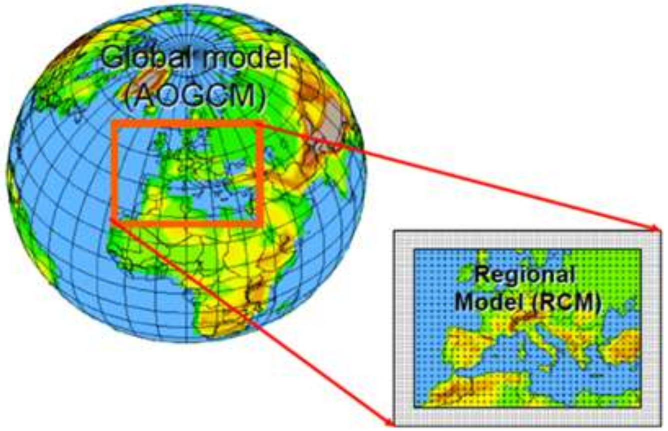
Climate Forecasting

Global RCP → Ensemble General Circulation Models (GCM) → Regional Climate Model (RCM) → Downscale And Bias Correct → Force Basin Hydrologic Model

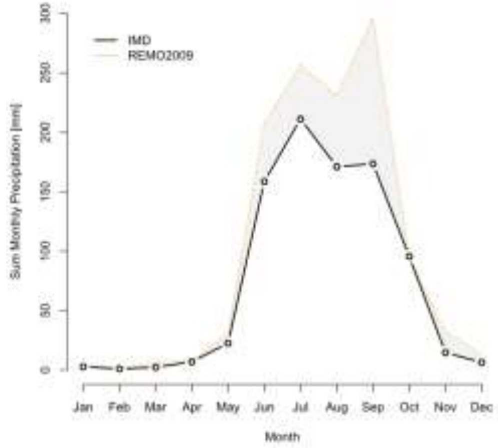
GHG Trajectory
as radiative forcing



Coarse spatial resolution of GSM
Calls for RCM



Statistical Downscaling to bias
Correct (Ekstrom et al 2015)



Input into
water module

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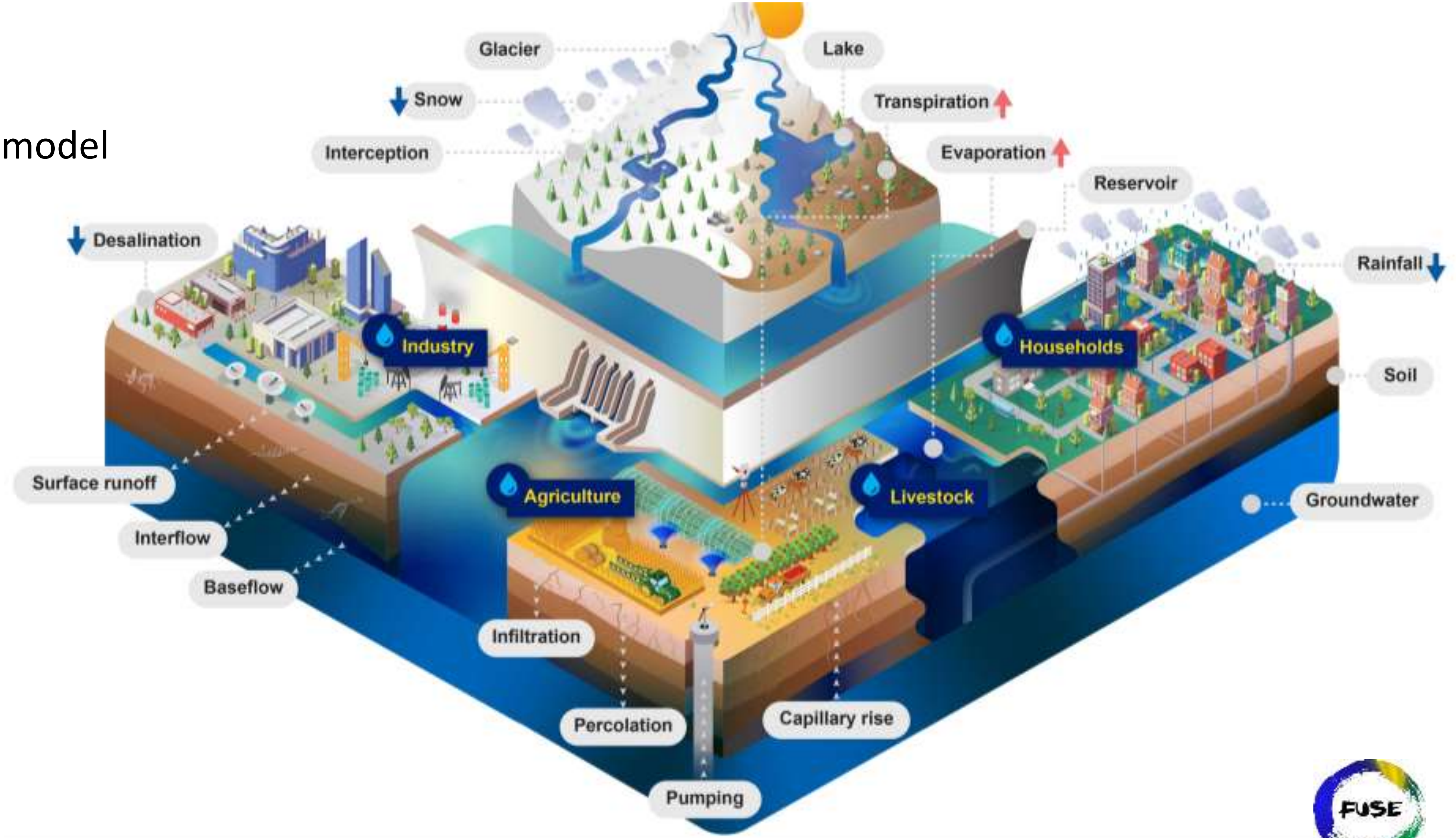
Water

Water Module

The Community Water Model (CWatM)

- Open-source
- Process-based hydrological model
- Connected grid of cells
- Daily water fluxes
- 1km resolution



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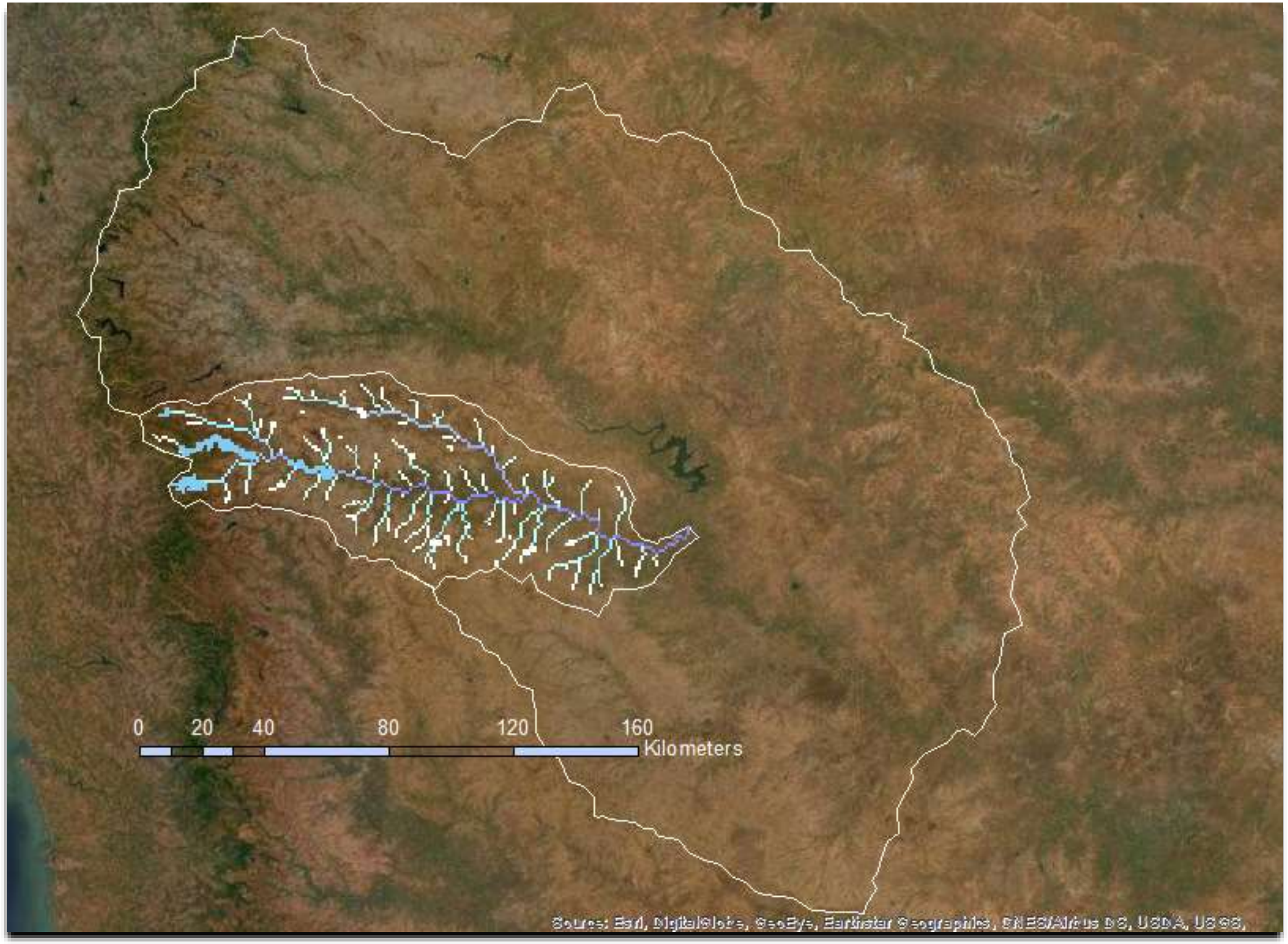
Preliminary results of CWATM



Bhima River Basin
- 7 districts
- 43 Talukas
- 55 reservoirs

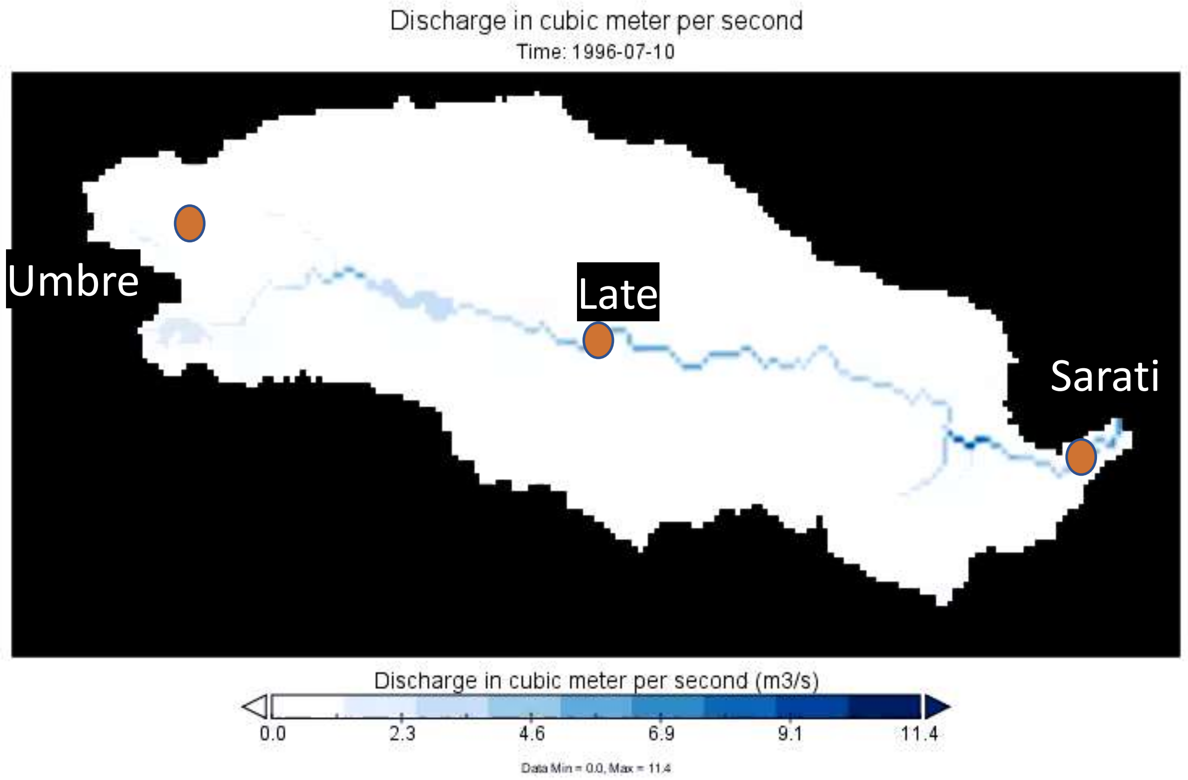
Nira River Sub Basin
- 2 districts (Pune, Satara)
- 8 Talukas
- 5 Reservoirs
- 1 Urban area
- Command Areas
- Canals

Network Legend

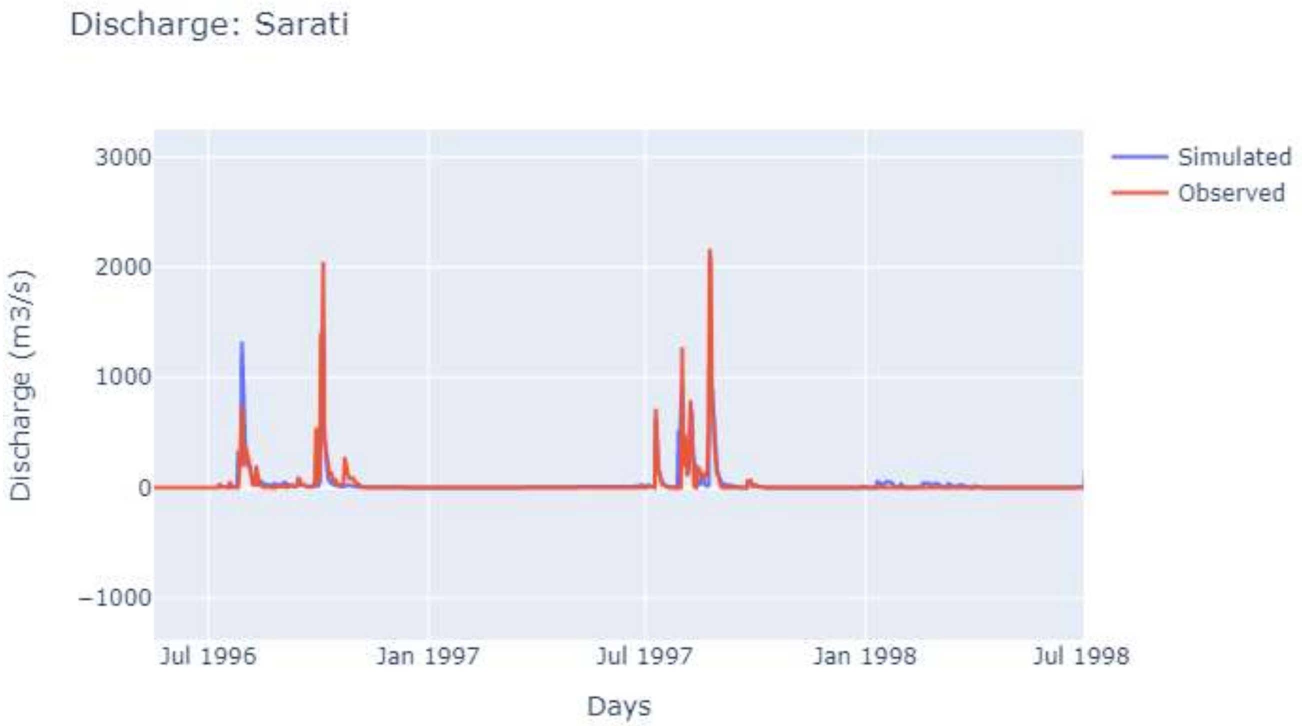
Farms
Pipes
Rivers
Canals
Reservoirs
Wastewater TP
Treatment Plants
Junctions
Command Areas

River discharge

- Kinematic Wave Routing
- Main output for calibration at various gauges
- Last gauge, Sarati, integrates the full basin and is used to calibrate with 10 years of observations.
- View monsoon and ephemeral rivers



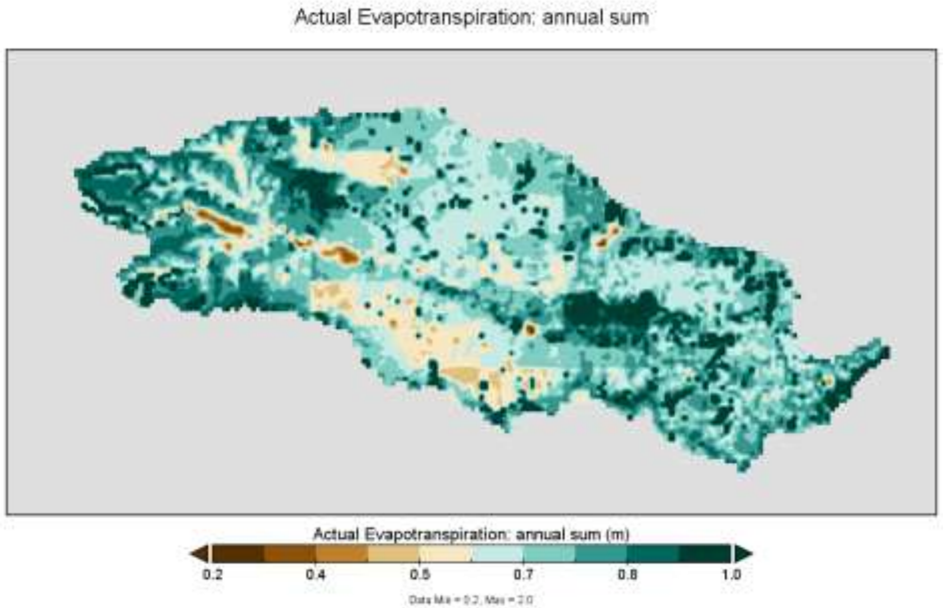
Two Monsoonal Pulses showing river discharge (m3/s), from July 1996



Evapotranspiration

- Sugarcane, sorghum, and rice are currently included in the model.
- First estimates of the specific region: No data to benchmark with.

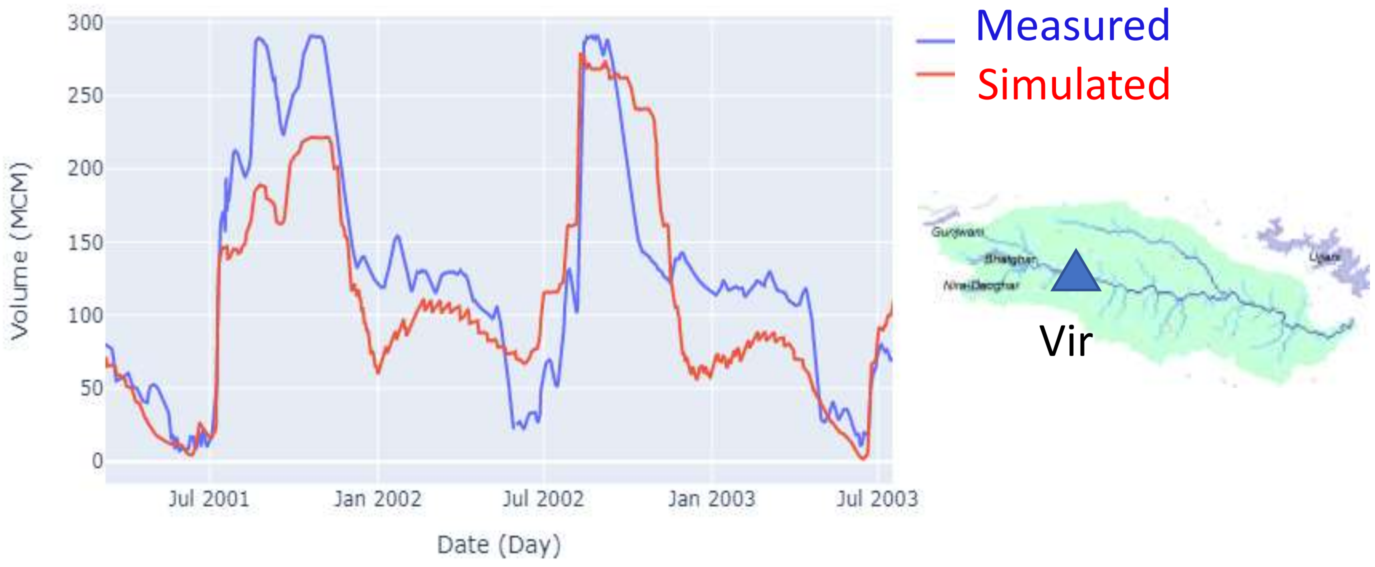
Data Gap: Crop-specific land use in time.



Reservoir Operations

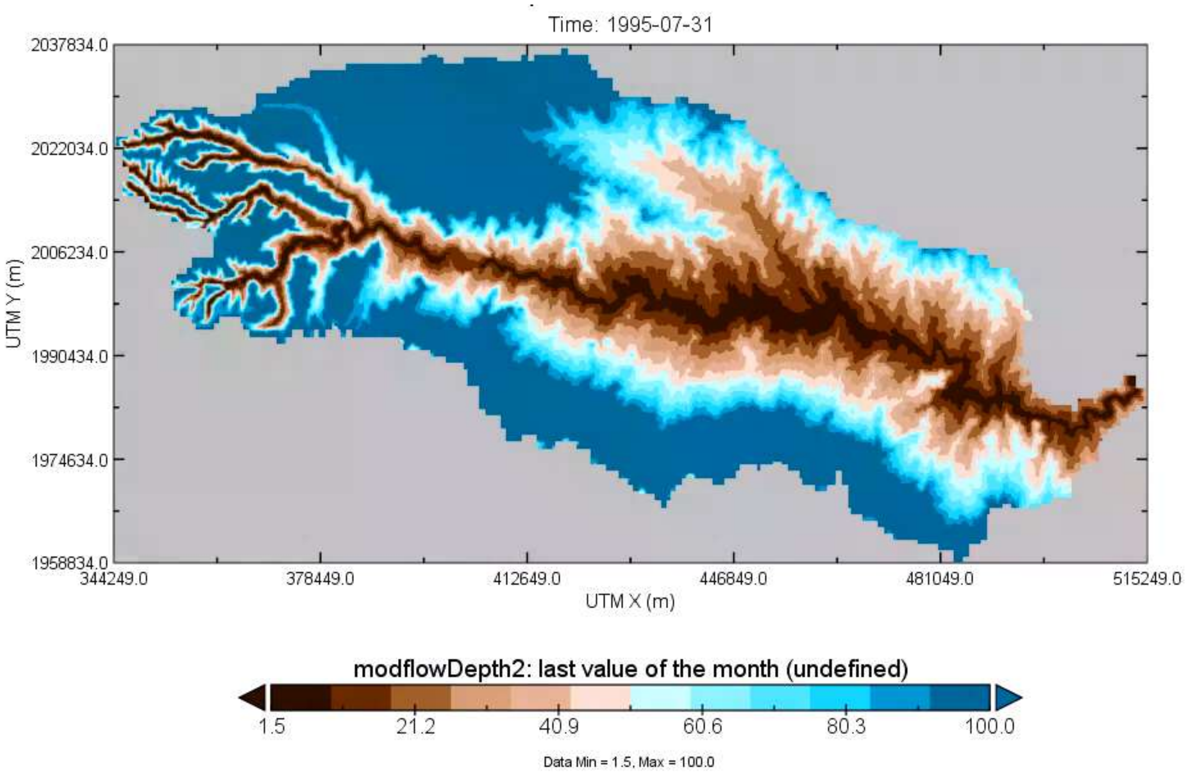
- Reservoirs distribute water to those within their command area.
- Reservoirs can leak along their canal distribution networks, recharging groundwater.

Data Gap: Reservoir operating decisions. Reservoir Inflow and Outflow necessary but not sufficient



Groundwater

Depth to groundwater



- Groundwater pumping is simulated within each cell to satisfy remaining water demands
- Reservoirs recharge groundwater by leaking along their canal networks

Data Gap: Depths to bedrock, groundwater storage

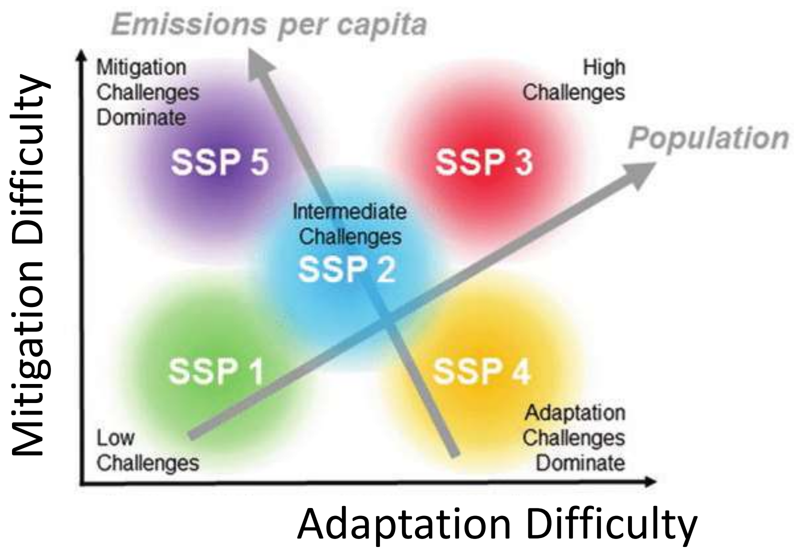
Urban

Urban Growth Forecasting

Estimate population

How many people?

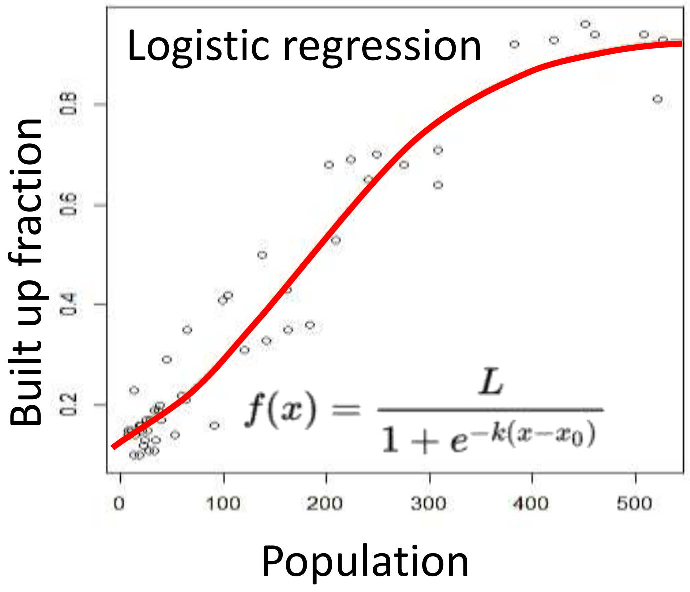
Based on different population projections (downscaled **SSPs**)



Correlate with built-up area

Translate pop. to built up area

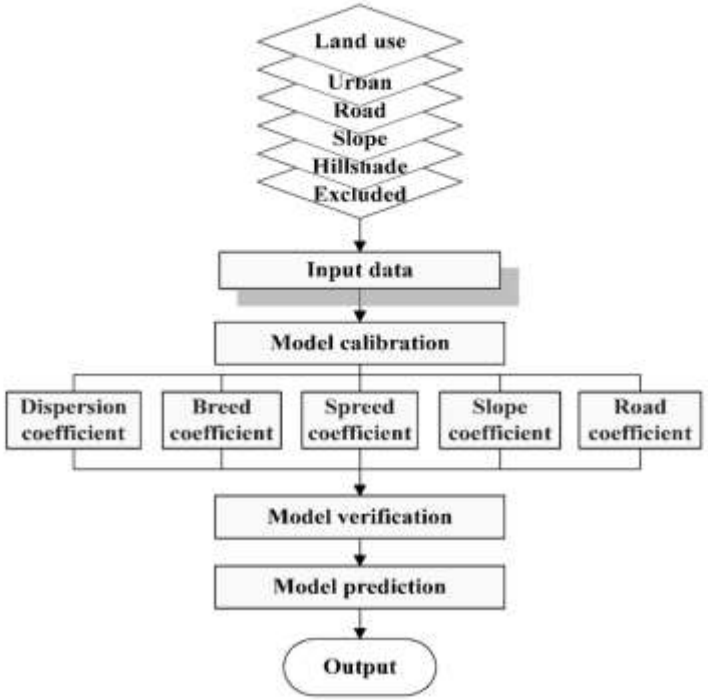
Integrate spatial and temporal aspects of urban growth



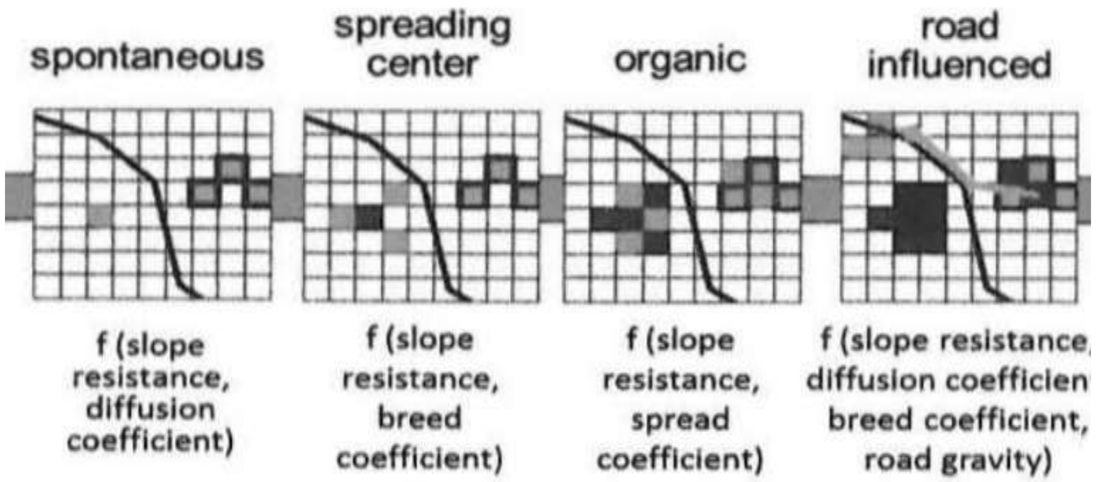
Project future urban land use change

Where will the people go?

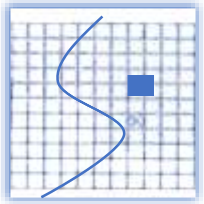
Use the cellular automata model, SLEUTH to find likelihood of urban development



Nexus Extension of SLEUTH model
Water Food and Slums



SLEUTH +



Water influenced urbanization
Use river locations as attractor, similar to road gravity

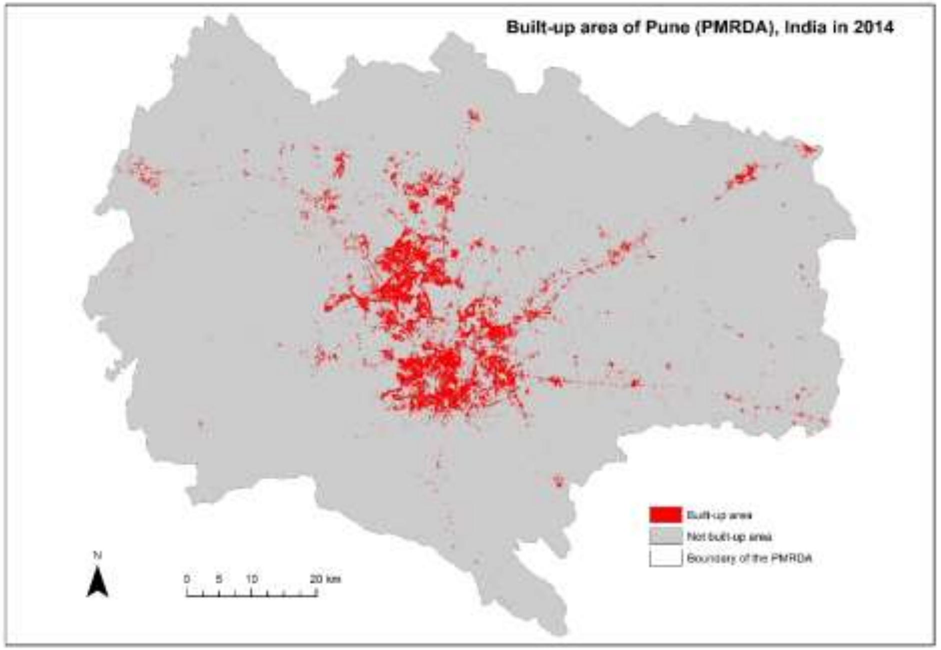
Agriculture influenced urbanization
Use agricultural profitability as resistance parameter

Slum-specific
Capture slum particularities in adapted CA model

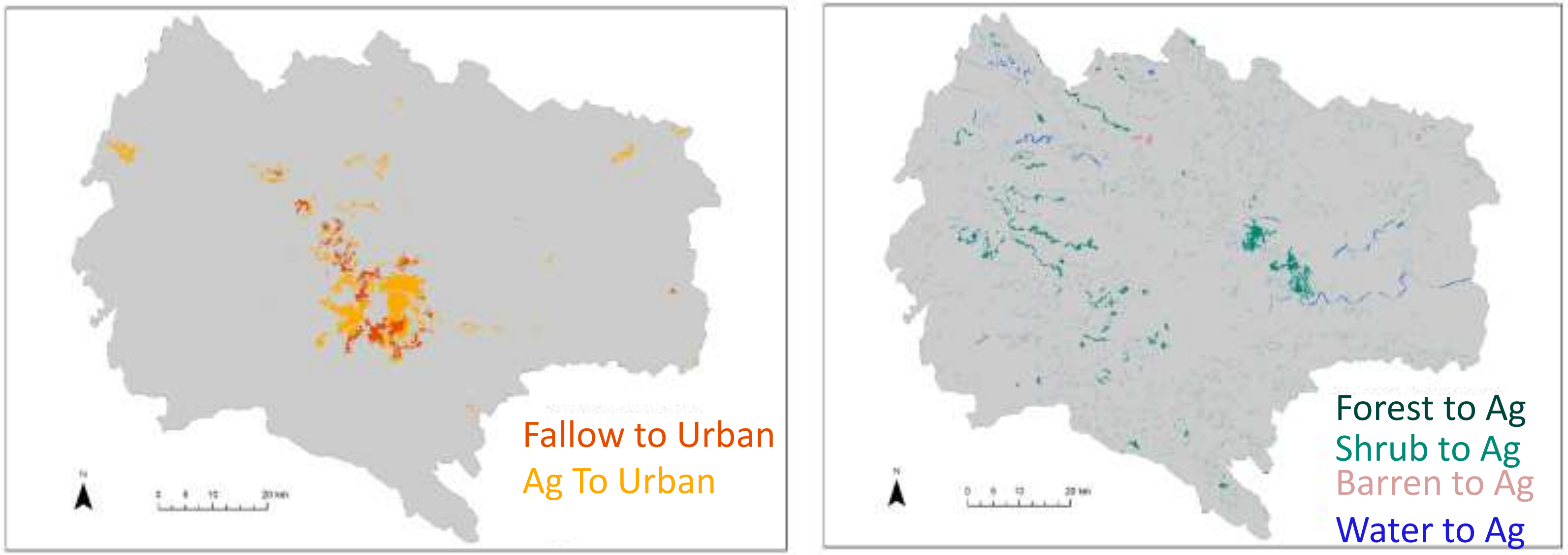
(adapted from Clarke, 2018)

Preliminary results of SLEUTH+

- Historical PMRDA (1975-2015):
  - 3-fold population boom (2.6 to 8.4 M)
  - 8-fold built-up expansion (47 to 384 km²)
- Built up area is displacing agricultural land and ag land is moving to forests and shrubland
- Water influence is decreasing (saturation effect or roads preceding?)
- Slums grow but not as fast as total built up rate

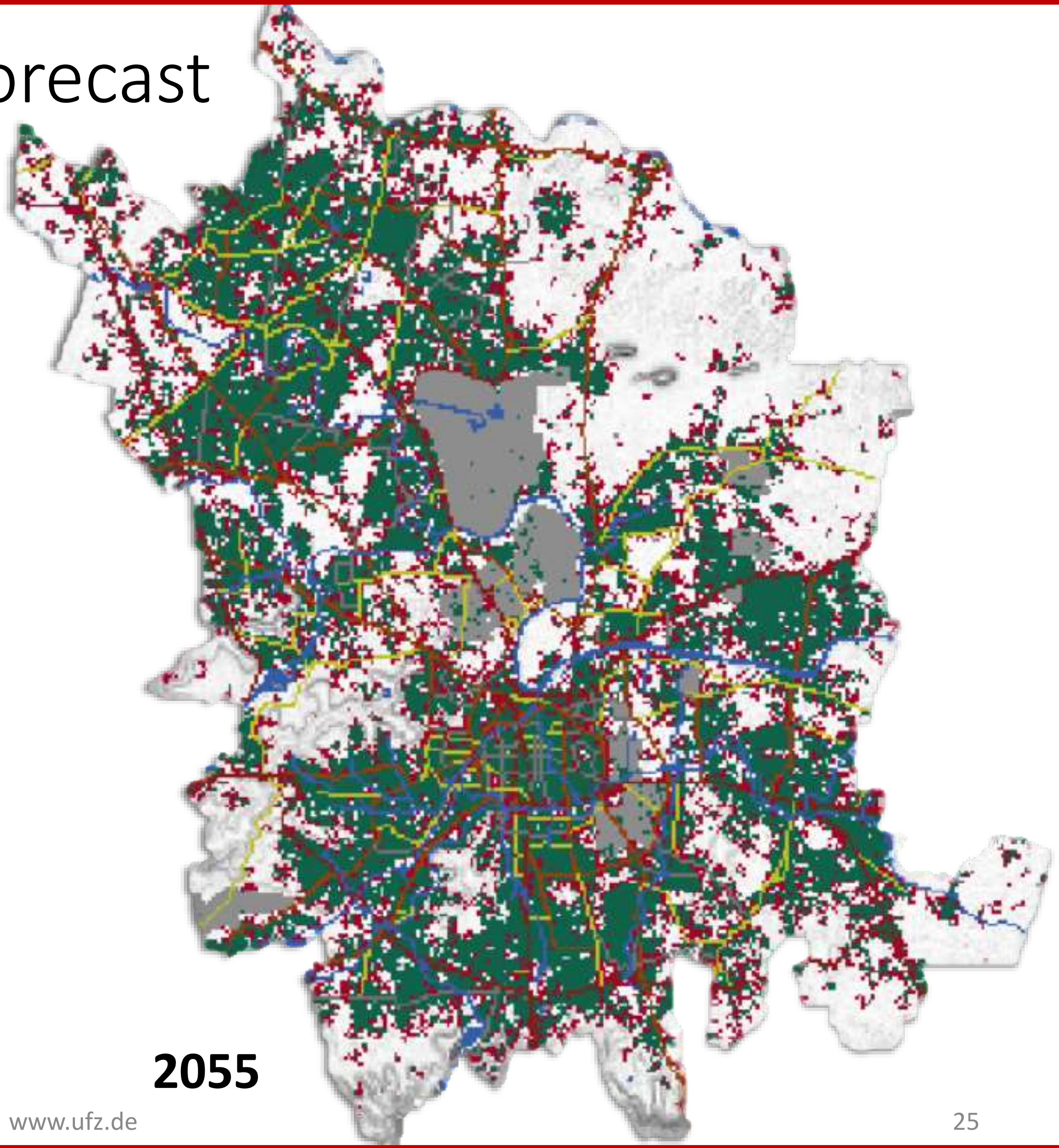


Land Use Change in PMRDA (1985-2005)



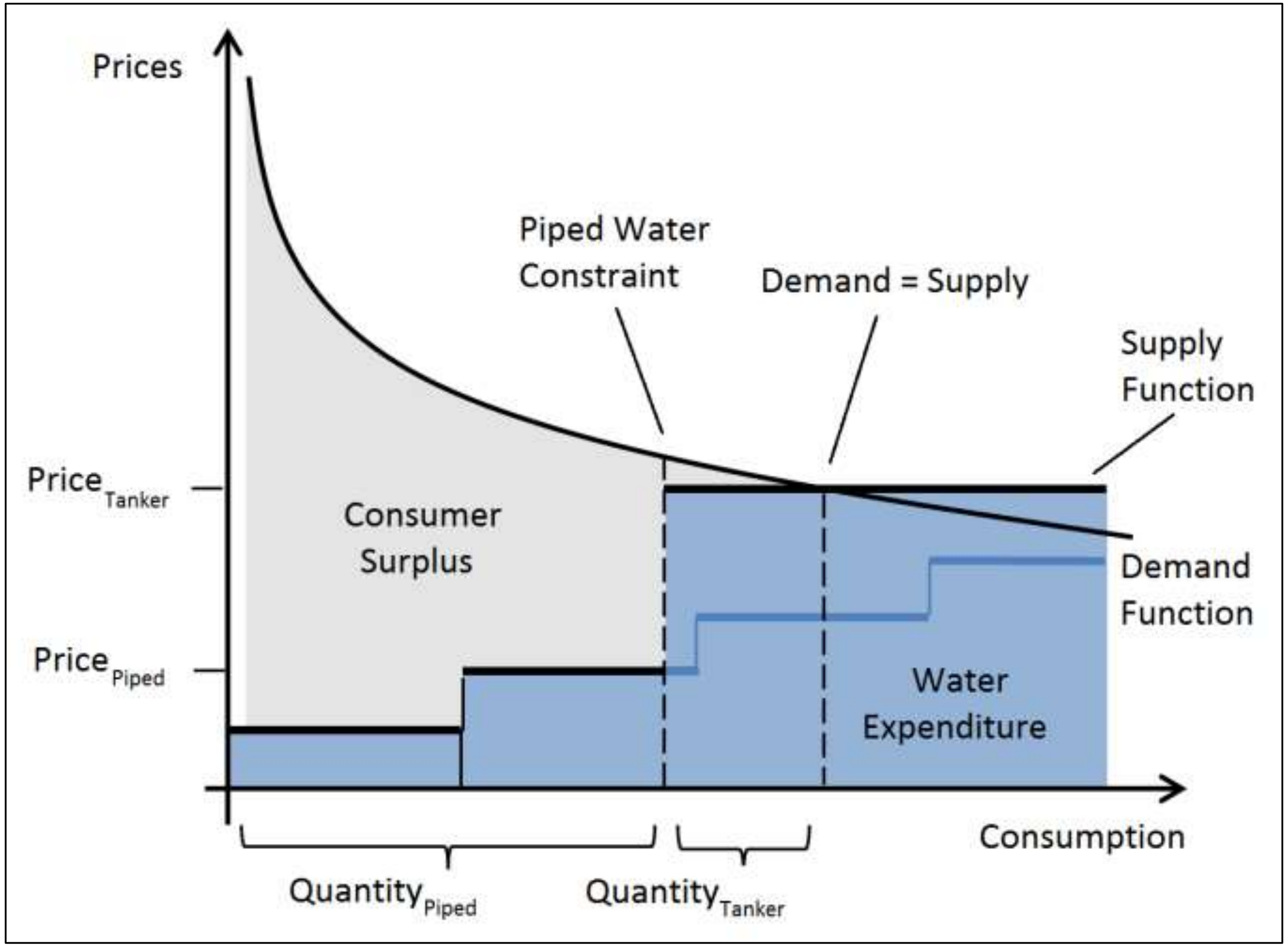
Preliminary results of Urban Forecast

- Urbanized forecast to reach 50.5% in 2055 (35.8% in 2015)
  - Compact growth, infill, ribbon development, slower than past



2055

Urban Consumer Model for FEW Resources



1. Demand Estimation

2. Resource Supply Curve

"Tiered supply curve" for resources that have limited supply hours (Klassert et al., 2015, based Srinivasan *et al.*, 2010)

3. Can infer unmeasured prices

Urban Demand Estimation

Survey Instruments

HH Consumer Expenditure Survey Type 1, 2
- NSS 68, 2011-2012
- NSS 66, 2009-2010

Indian Human Development Survey
- I (2005)
- II (2011-2012)

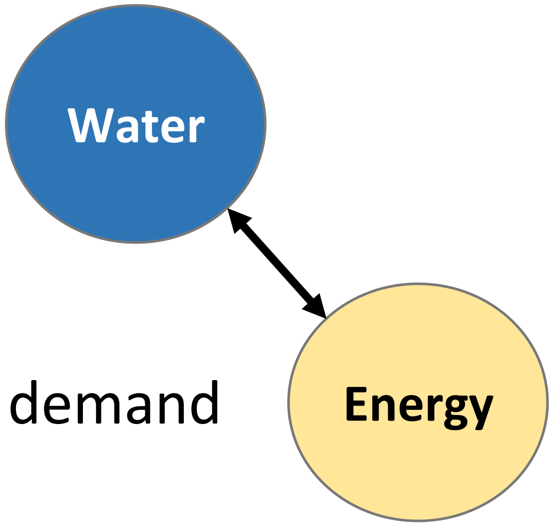
FUSE Pilot Survey

Main Insight: Importance of energy-water nexus at HH level

95 % HH In Urban MH receive <10 hours piped water supply per day
>> 95% of these consider this availability adequate

83 % of 101 HH receive less than 7 hours daily piped water supply
82 % of 95 HH receive one per day piped water for 3.4 hours
37 of 93 HH spend time to secure water (waiting, walking, collecting)
98 % of 93 HH receive 24 hour electricity supply

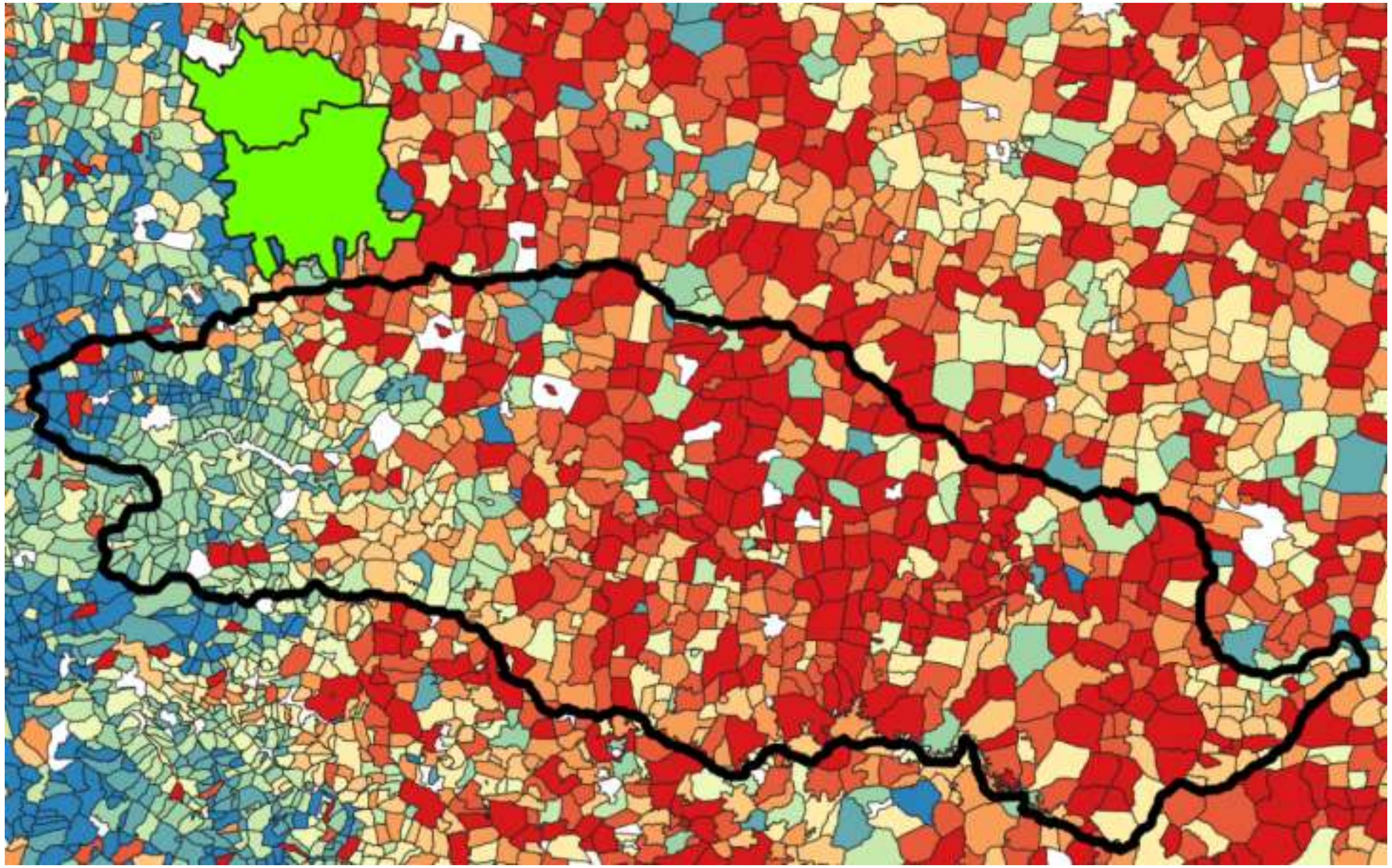
- Slums consume less water and have lower electricity demand
- HH size affects water demand, electricity and LPG demand
- HH with water storage tend to have higher electricity demand
- Water consumption positively correlated to HH LPG demand
- Increase in LPG consumption and water storage results in more water demand



Urban Demand Estimation

Village-level data available on:

- Well type
- Household size
- Monthly expenditure (income proxy)
- Education, literacy and school access
- Rural/ urban
- Distance to cities
- Businesses employee number
- Electricity supply

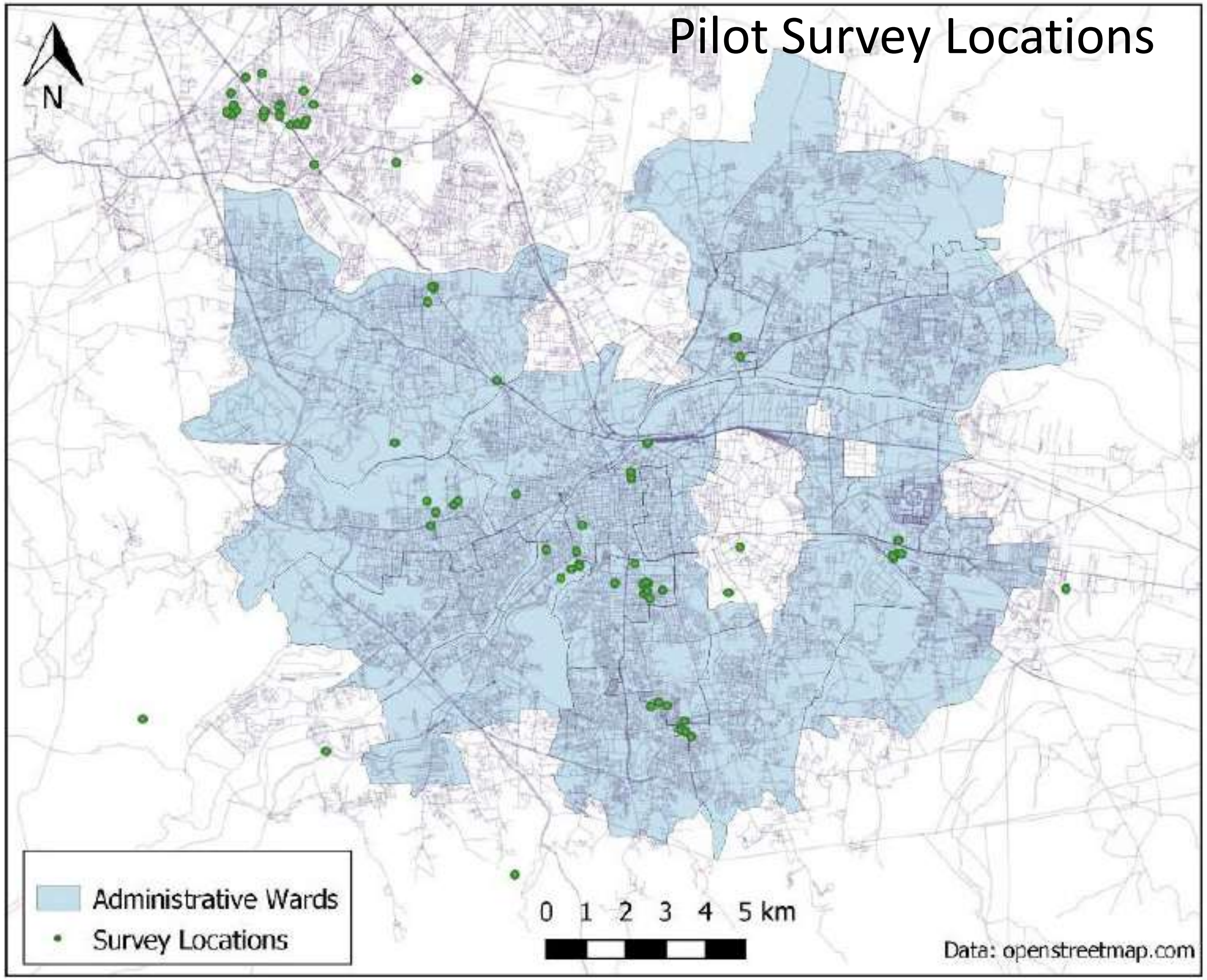


Data Gap: missing unit level data for nexus-related studies

FUSE Household Survey to Collect Data

Pilot May-June 2019
Pune and Pimpri-Chinchwad
112 door-to-door interviews
- urban, formal, slums
- Local language
- 300 + questions

Full Jan 2020
Households (n=2000)
Cooperation with Gokhale
Prep, Train, Test, Implement
Commercial (n= 250)
Anonymous in-person interview (no taping)
Structured, quantitative (~40min)
In Marathi
In Pune Metro and surrounding area
Using WB App Survey Solution



FUSE Household Survey Example Questions

Water

9 water sources: piped, tanker, private well, public well, canned water jar, bottle water, rainwater, pond, other
3 seasons : winter, summer ,monsoon

1. **water source**(s) and percentage used in past year
2. months you think are **water-scarce**?
3. monthly water **consumption**?
4. water storage **equipment**?
5. Water **payment** type and amount

Energy (Kerosene, LPG, Electricity)

1. **payment** in Rs/month by season
2. **price** in rs/liter per season
3. quantity **consumed** per month in L/mo by season
4. from where (shop, market, other)

Economics

1. Living space in sq. ft
2. Number and type of appliances
3. Monthly income for all members Rs/month
4. Home ownership

Food

1. Percent of HH income used for food?
2. How much do you spend on food per month? in Rs/month
3. Seasonal variation in food expenses?
4. Ration card Type?
5. What factors influence food purchase decisions from most important to least (nutrient content, calorie, taste and texture, prestige, availability, safety, region of production)

Additional FUSE Activities in Pune

Water Diaries

- 50 household document water collection and use for a week
- Focus on locations with high herterogeneity in water access

In-depth household interviews

- 20 households concerning water collection, storage, usage behaviors

Small Tanker Operator Survey

- 20 structured interviews with tanker operators to understand cost, pricing, business
- Semi-structured expert interviews

'Clicker Study'

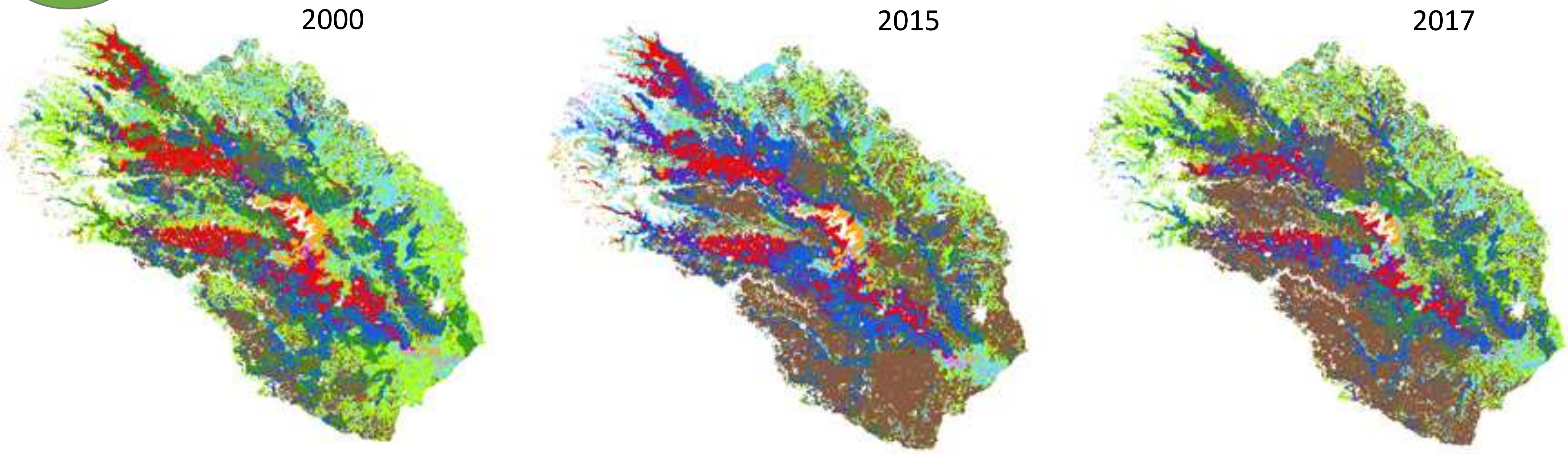
- Estimate tanker volume market by counting tanker trucks passing by strategic observation points

Migration Interview

Agricultural

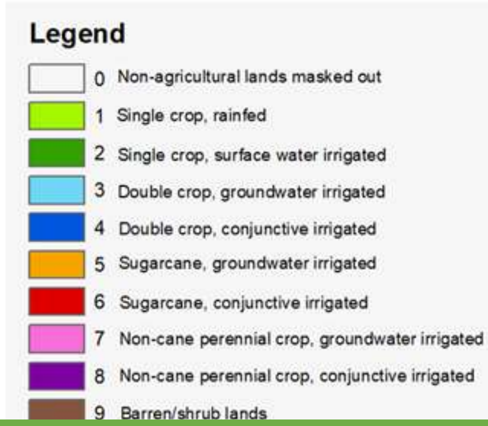
Ag Module

Optimization and Machine Learning for Farmer Decisions



Farmer Decision: Optimization method using positive math programming (PMP) to select a crop --- Requires parameter calibration to observation

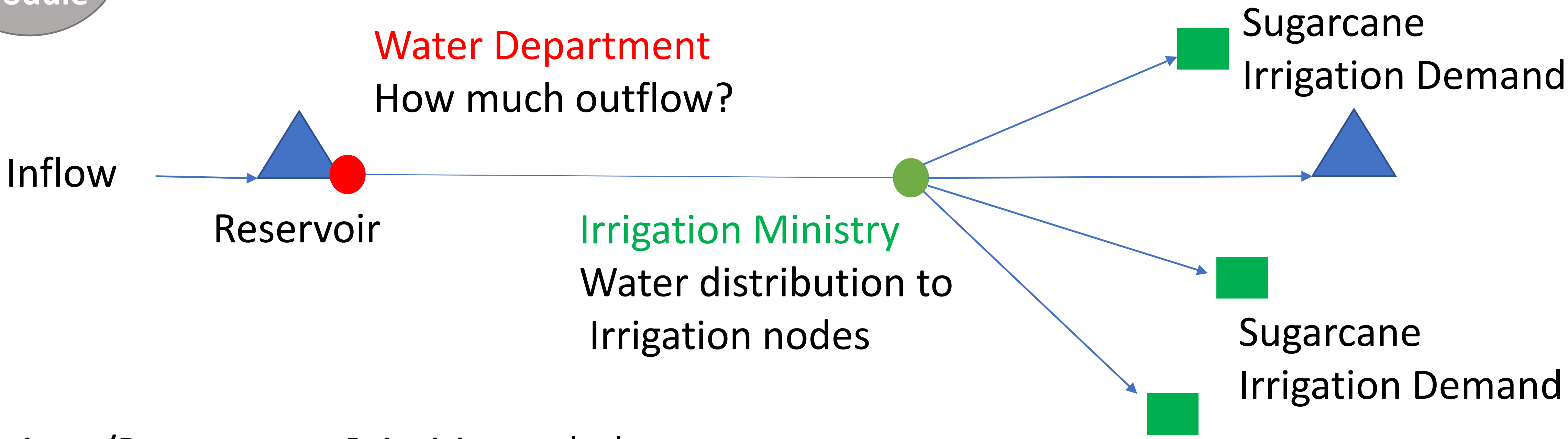
Unsupervised land classification



Data Gap: **spatial** crop maps with which to validate; price and cost info.

Agent Network

Agent Network Module



Ministry/Department Priorities coded

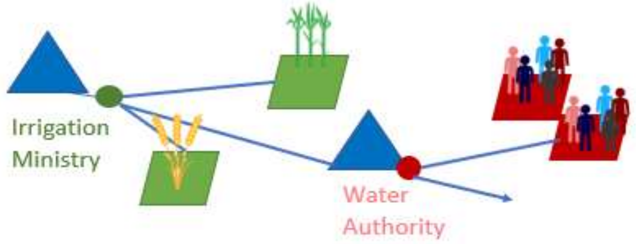
Policy Change Tests

- Ex: sugarcane weight (to reflect support)
- Ex: spatial/regional weight
- Ex: flood protection operating rule
- Ex: additional capacity/infrastructure

Conceptualizing the Nexus Model

Agent Network Module

Tests policy decisions by institutions and managers to supply resources



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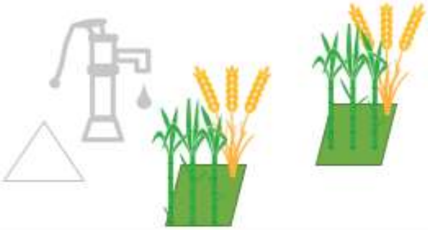
Determines the crop type, crop area extent, and water quantity demanded by crop and source



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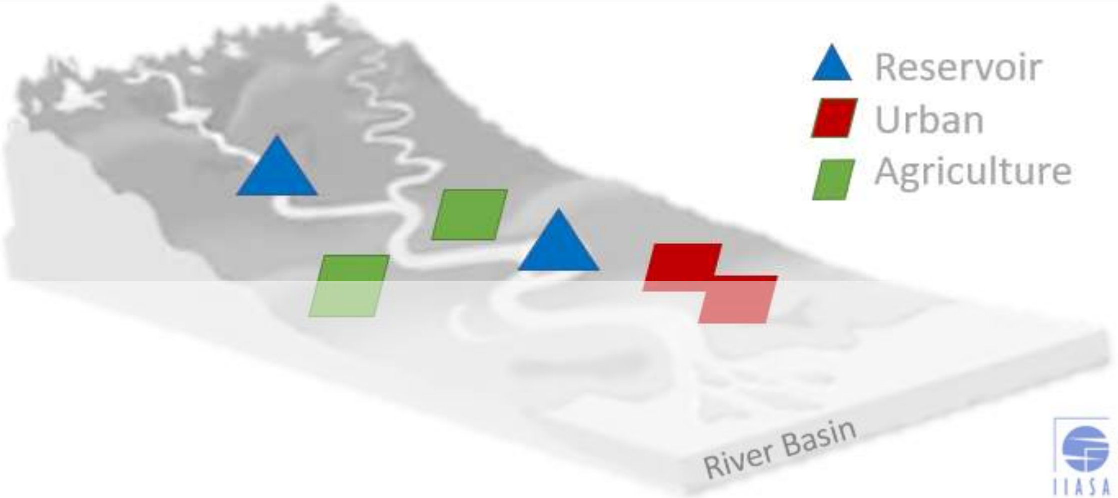

*Energy Module Not Yet Shown

Data Needs

Some General Data Needs

Urban

- Actual urban water and energy use spatially by sector and time
- Focus on historical time series by spatial units
- Aggregate water use by cities (PMC, PCMC, PMRDA, MIDC)
- Piped distribution network map
- Water and energy supply system capacities and supply duration by ward or distribution zone
- Big consumers and changes in use
- Urban flood information

Agricultural

- Observed land use (crop specific and in time, months)
- Observed crop yield (Production and Area)
- Crop prices at higher resolution than state
- Production Costs (spatial or higher resolution than state)
    - land costs
    - input costs (labor,
    - Water costs (surface water and groundwater)
- Irrigation water used (amount and source)
- Historical drought information

Water

- Ujjani inflow for recent years
- Water audit spreadsheets for more years
- Water allocation rules among crops or within ag
- Annual water withdrawals
- Monthly water supplies
- Reservoir operating rules
- IMD Soil Moisture and Evapotranspiration
- Evaporation station locations
- 38 gauge River Discharge Daily 1980-2019*
- 55 Reservoir Daily Inflow, Level, Storage, Discharge from Flood Control Cell Sheets*
- Water Accounting Sheets for missing 44 Reservoirs and longer time for all*
- Reservoir Top bottom and Crest*
- Irrigation water use
- Ground level and pumping*
- Flood Control Levels (FCL)*

* Some obtained previously, need missing years/locations to fill data gaps

Exploring Potential Policy Interventions for Pune

Climate

Climate policy

- Mitigation/ Adaptation to Extremes
- Green Infrastructure

Water

Governance

- Enforcement of the existing regulations
- Basin-wide economic optimization
- Transferable water entitlement system

Supply

- Distribution Rules
- Additional infrastructure
- Local solutions RW harvesting

Demand

- Restructuring of water tariff system
- Reduce non-revenue water

Agriculture/Food

Sugar sector

- Removal of sugar price supports
- Sugarcane use for biofuel production

Irrigation

- Adoption of new irrigation technology
- Water reallocation to priority crops

Urbanization

Urban policy

- Planned Development

Energy

Energy policy

- Biofuel and Solar PV adoption
- Capacity expansion

Preliminary Insights

- **Nexus focus –** model and quantify the benefits of overcoming silo thinking
- **Co-Creation** – stakeholders aware of challenges
- **Evaluation –** limited capacity to assess policy solutions
- **Stakeholders -** Eager for systems approach
- **Data acquisition** – difficult, top down
- **Pune** – civil society – pro-active and lower expectation of government

Questions/ Comments