Due to animation used in presentation, formatting in PDF file may be inconsistent.

WOODS INSTITUTE FOR THE ENVIRONMENT
STANFORD UNIVERSITY

Global Freshwater Initiative:

Developing Strategies to Promote the Viability of Long-term Freshwater Supplies for People and Ecosystems

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Global Freshwater Initiative

Woods Challenge

- global water resources problem
- interdisciplinary approach

Our Response

Assessed what is needed.

There is no single global water crisis – problems are regional.

- How through regional studies can we provide global guidance?
- What is the best approach to improve the **scientific basis** for water resources management?

Integrated hydrologic-economic policy-evaluation models.

Mexican Water Crisis

Example

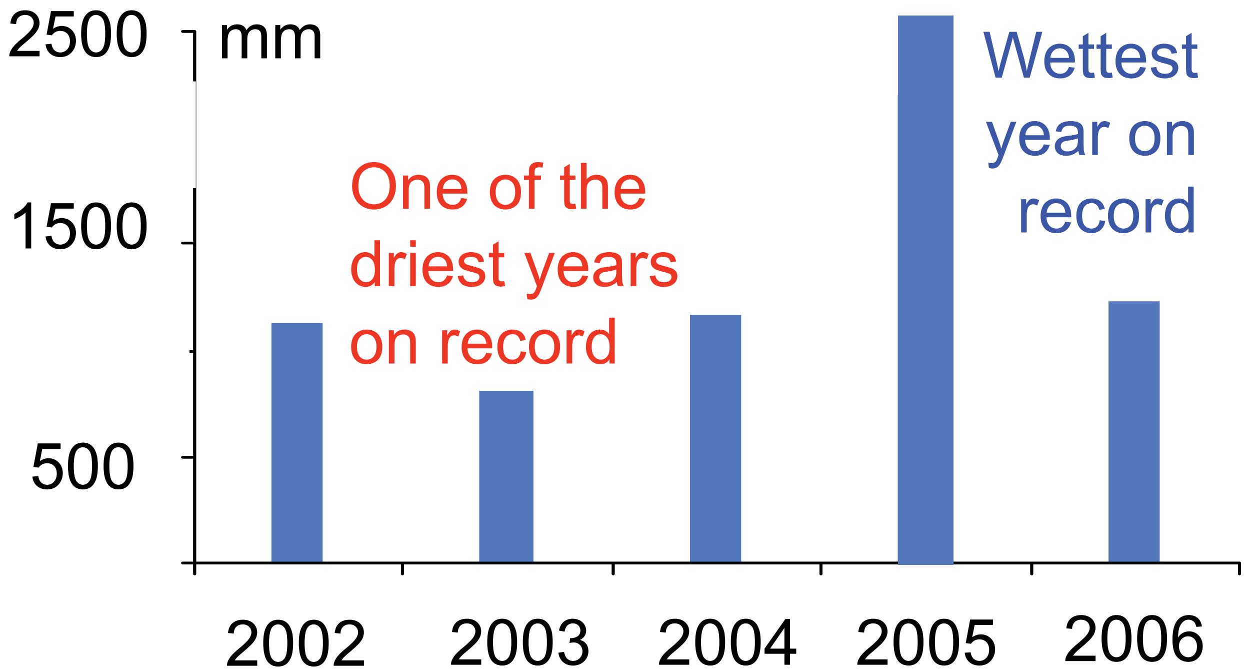
Intermittent water supply Chennai, India

Coastal city of 4.5 million people in Tamil Nadu

No major city in India has 24 x 7 utility supply.

Climate

Rainfall Record (2002-2006)



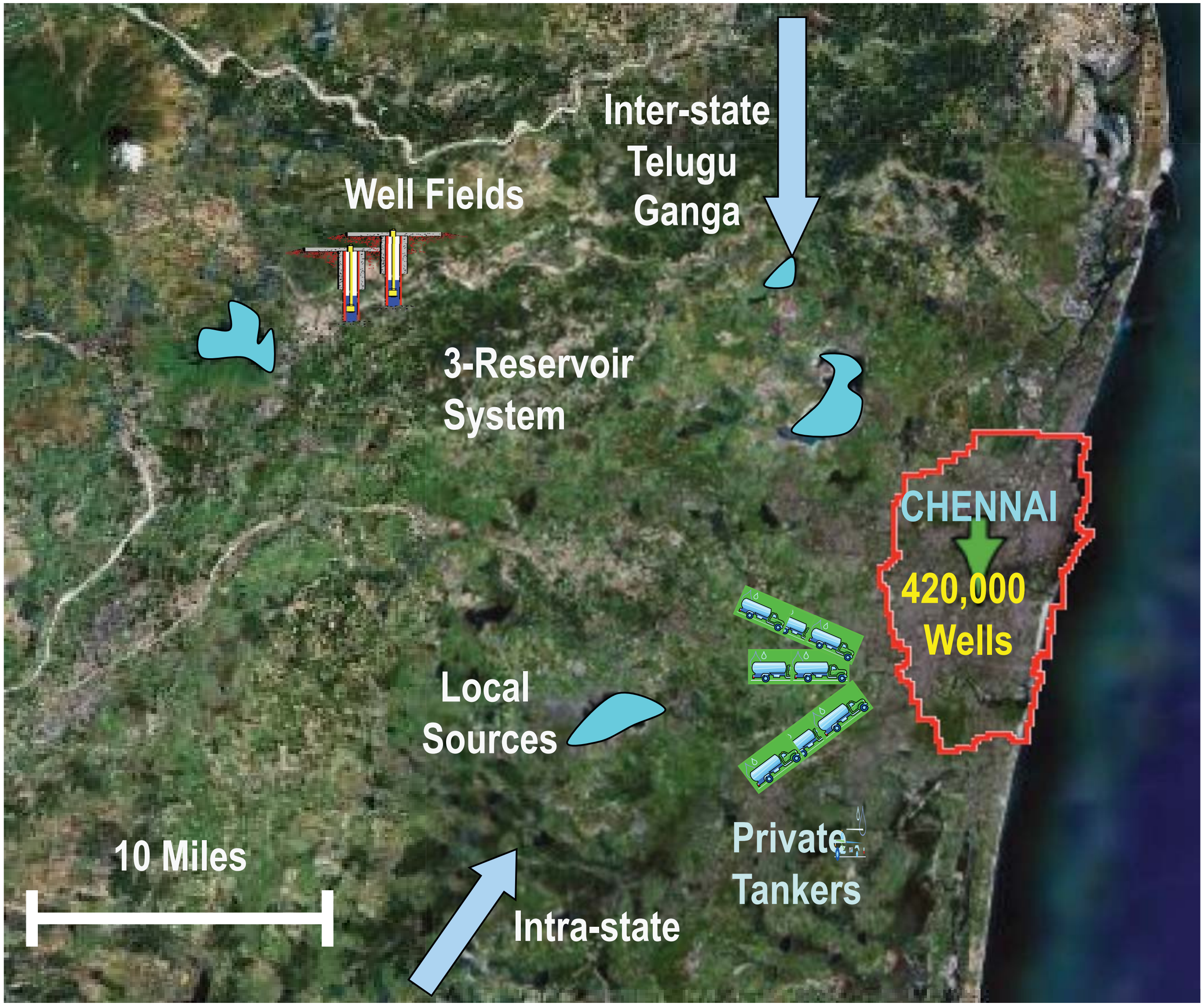
Wet season

Oct-Dec from NE monsoon

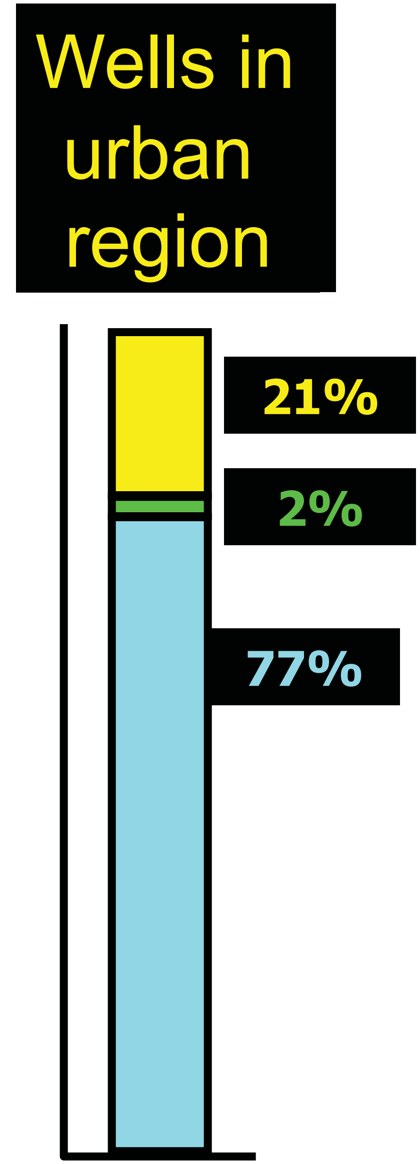
Highest groundwater levels in January and lowest in July

Crops

Rice, peanuts, grains, sugar cane, vegetables



Inter-state
Telugu
Ganga
Well Fields
3-Reservoir
System
CHENNAI
420,000
Wells
Local
Sources
Private
Tankers
Intra-state
10 Miles



Wells in
urban
region
21%
2%
77%

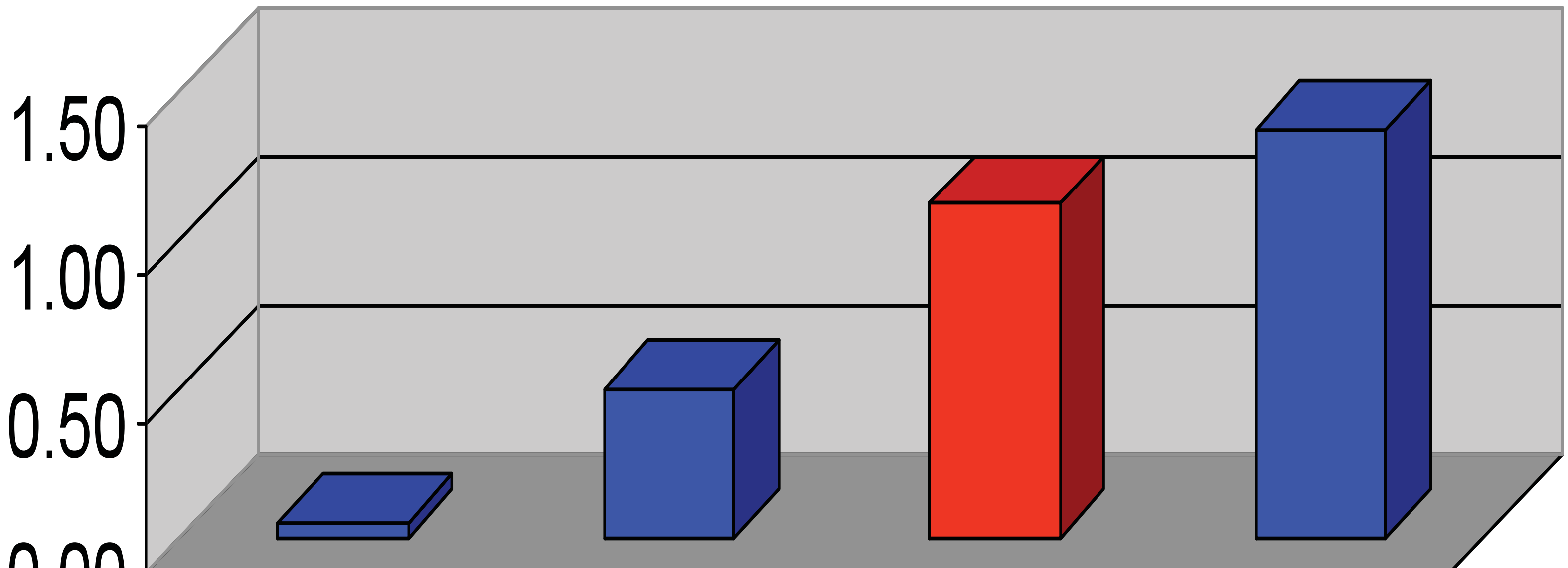
The problem

- In 2003-2004, Chennai suffered a water crisis.
- Reservoirs dried up.
- Piped supply was shut down.
- Private wells went dry.
- The entire city was supplied by tankers and remaining private wells.

15 liter or 4 gallon
"pots" of water

Per capita water use is ~100 liters/day or less than ¼ of that in the US

Utility's solution – Add expensive supply



	Piped supply	Private wells	Desalination	Tankers
Price $	0.05	0.50	1.13	1.38

Price in $ per 1000 liters

US GDP per capita $46,000 versus $3,000 in India

Question

What policies might be effective in preventing a recurrence of such a crisis?

For example

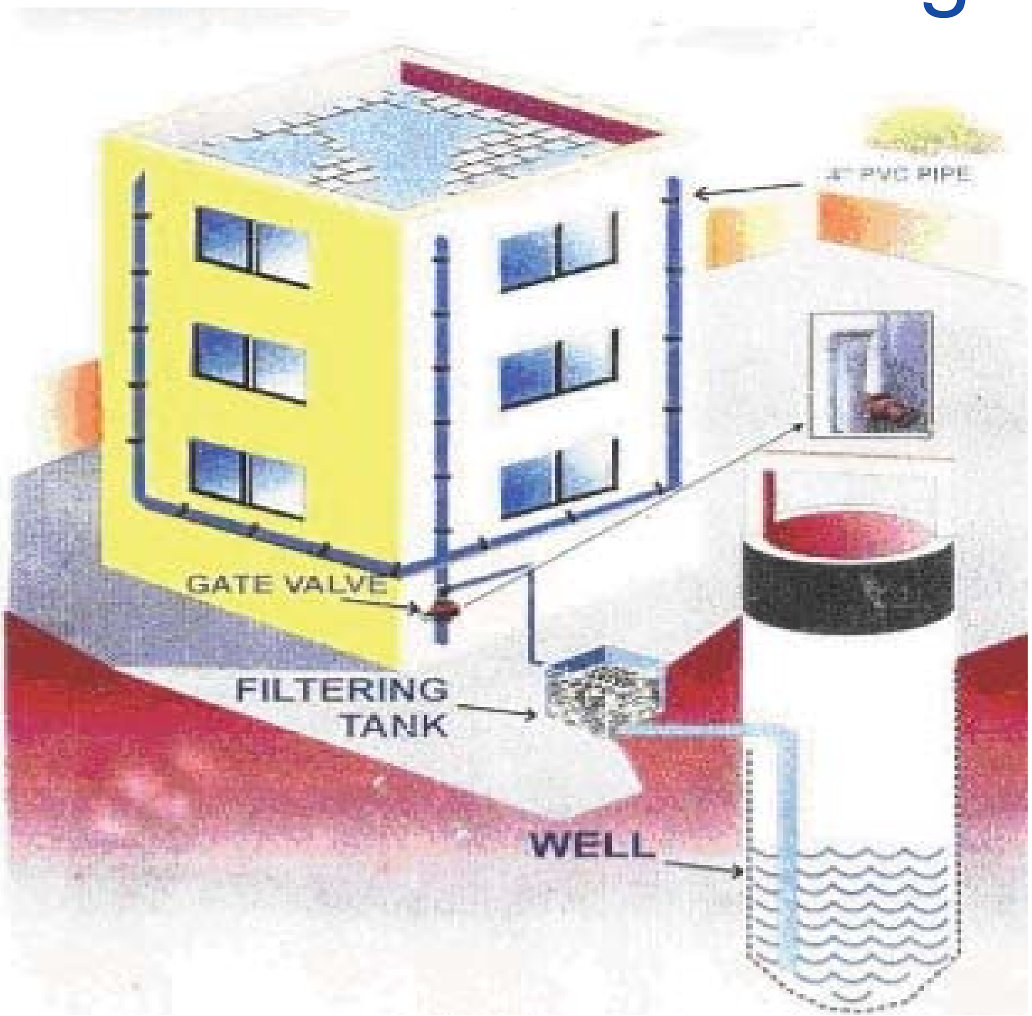
New desalination plants

Expand reservoirs

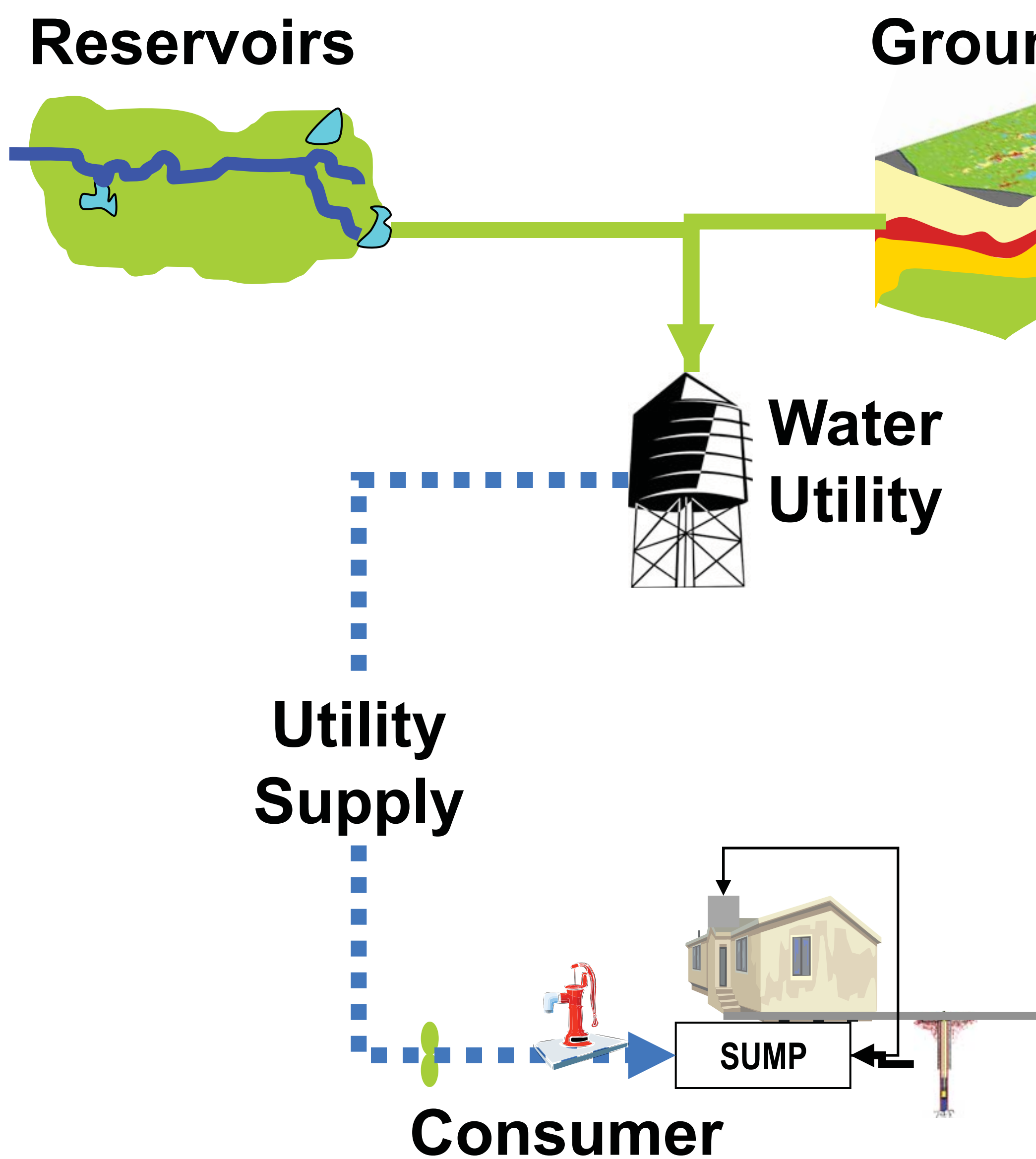
Rainwater harvesting

Community-based solution

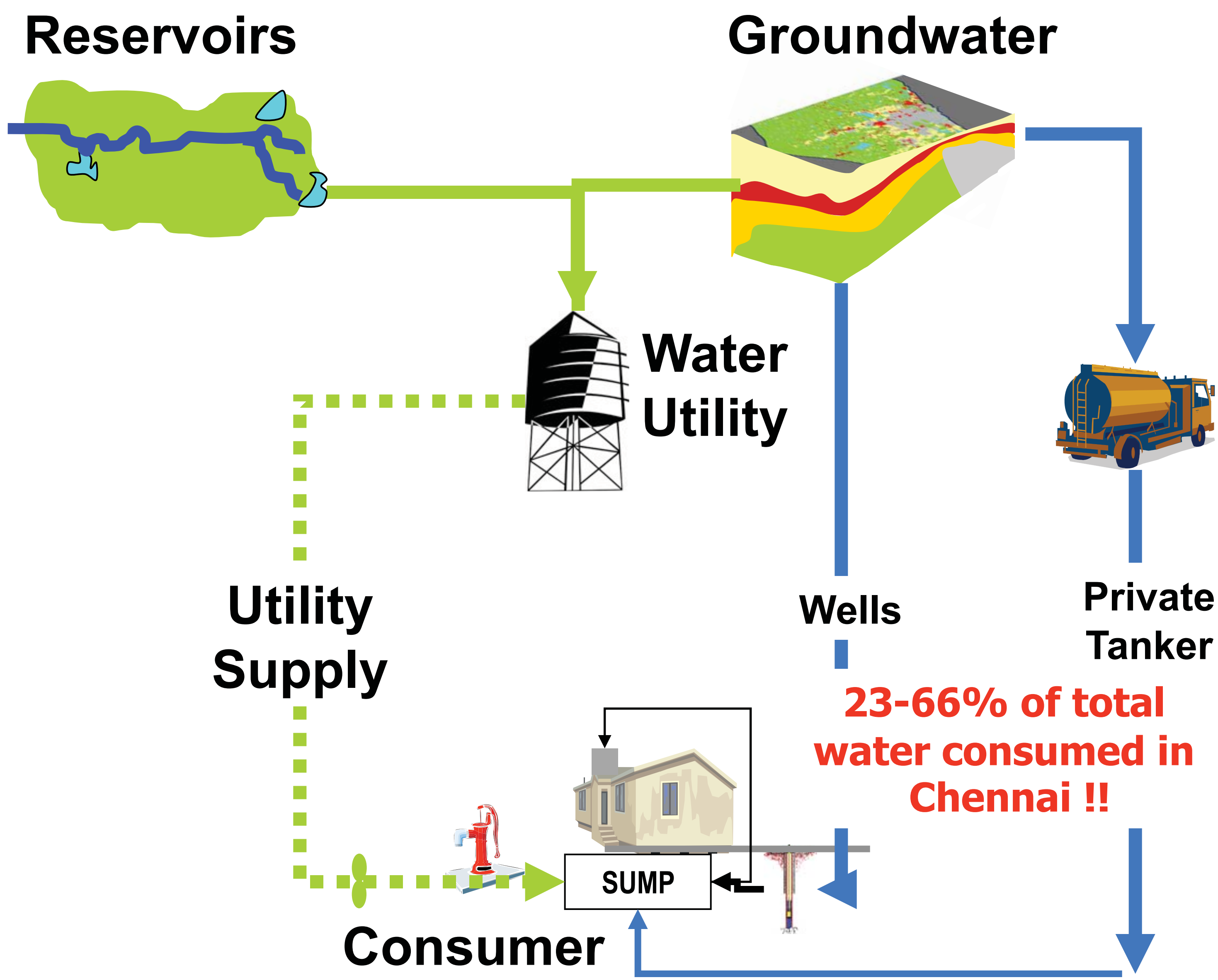
rainwater harvesting



Centralized water supply system



Actual water supply system



Integrated model

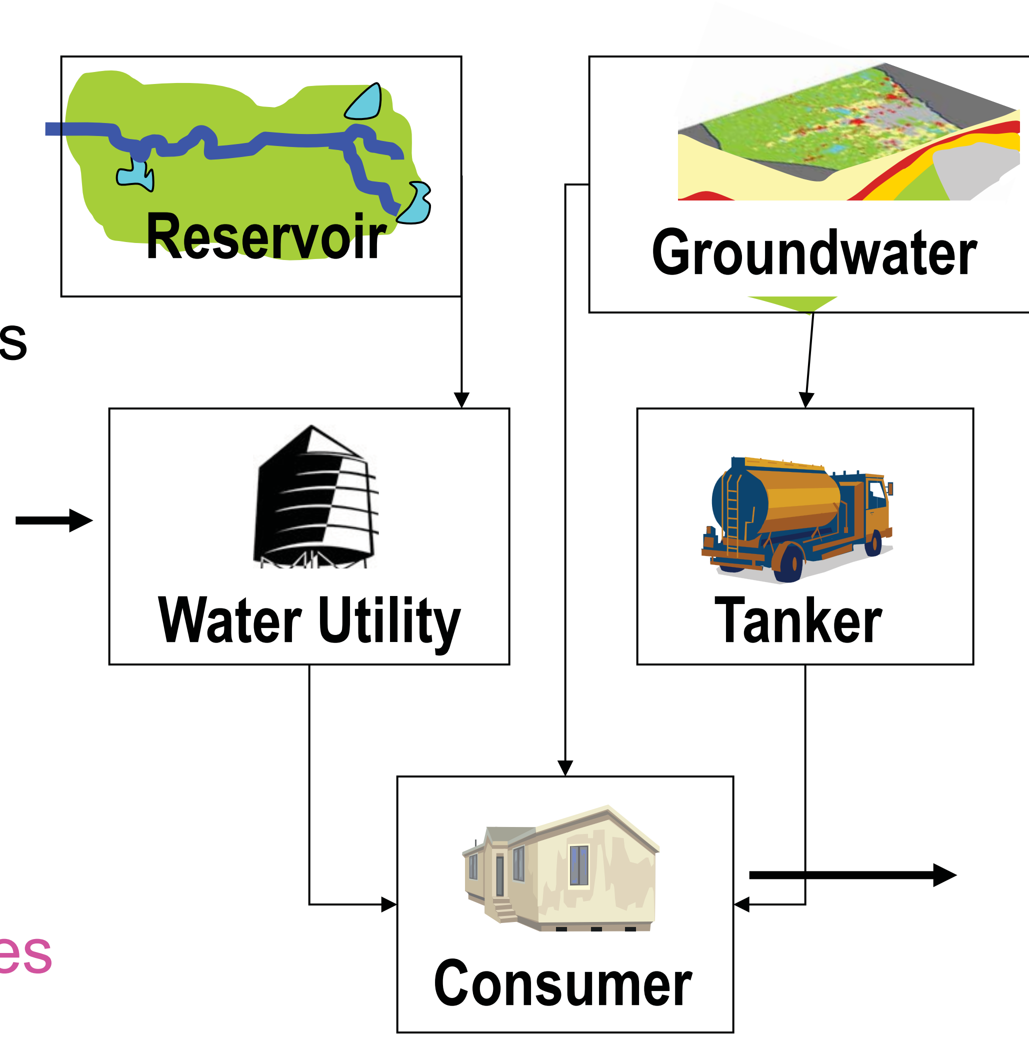
INPUTS

Data
Rainfall
Land use
Demographics

Calibration
Aquifer
properties

Opportunity
cost of time

Operation rules
for utility

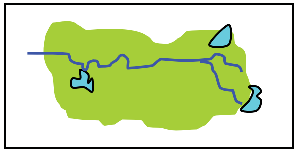
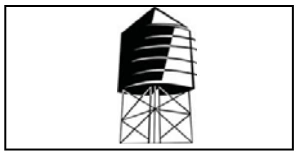
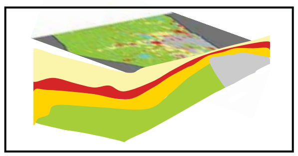
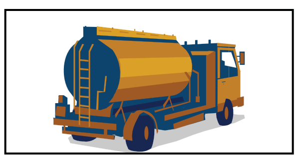
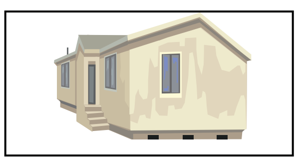


OUTPUTS

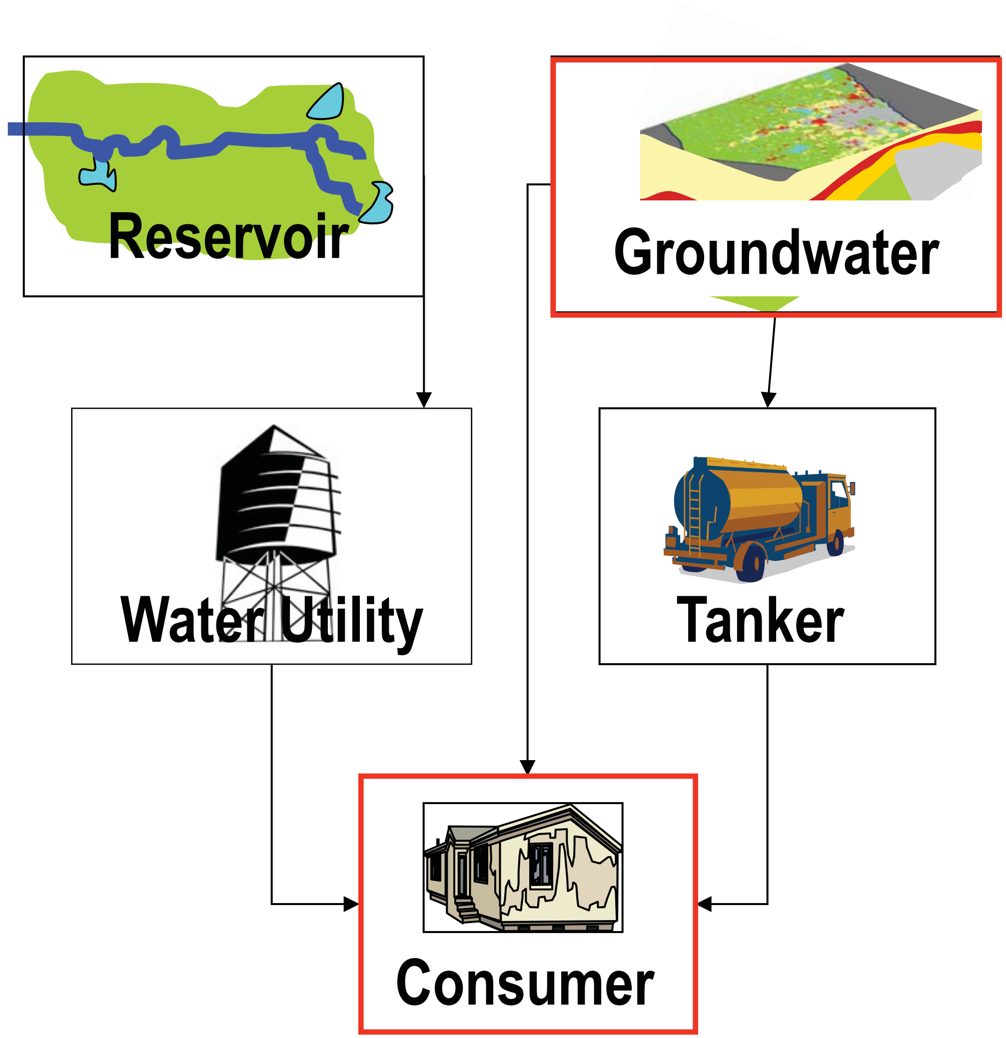
Quantity
consumed
by source

Consumer
Surplus $

Integrated Model Outputs

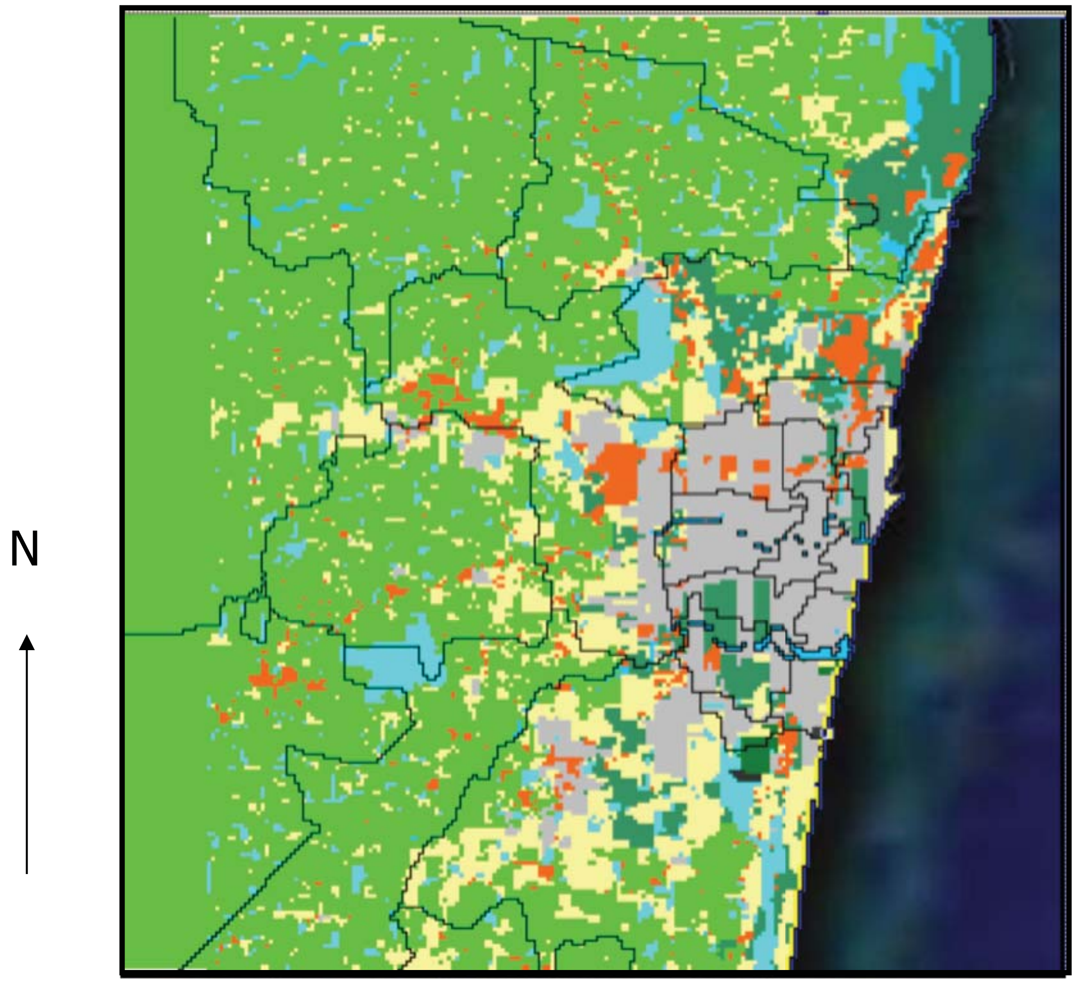
		Module	Output
SUPPLY MODULES		Reservoir Module	Reservoir storage and release to utility
		Utility Module	Utility supply available to consumer
		Groundwater Module	Available GW and dry wells
		Tanker Module	Quantity of tanker water
DEMAND MODULE		Consumer Module	Water demand by mode per consumer category

Integrated model

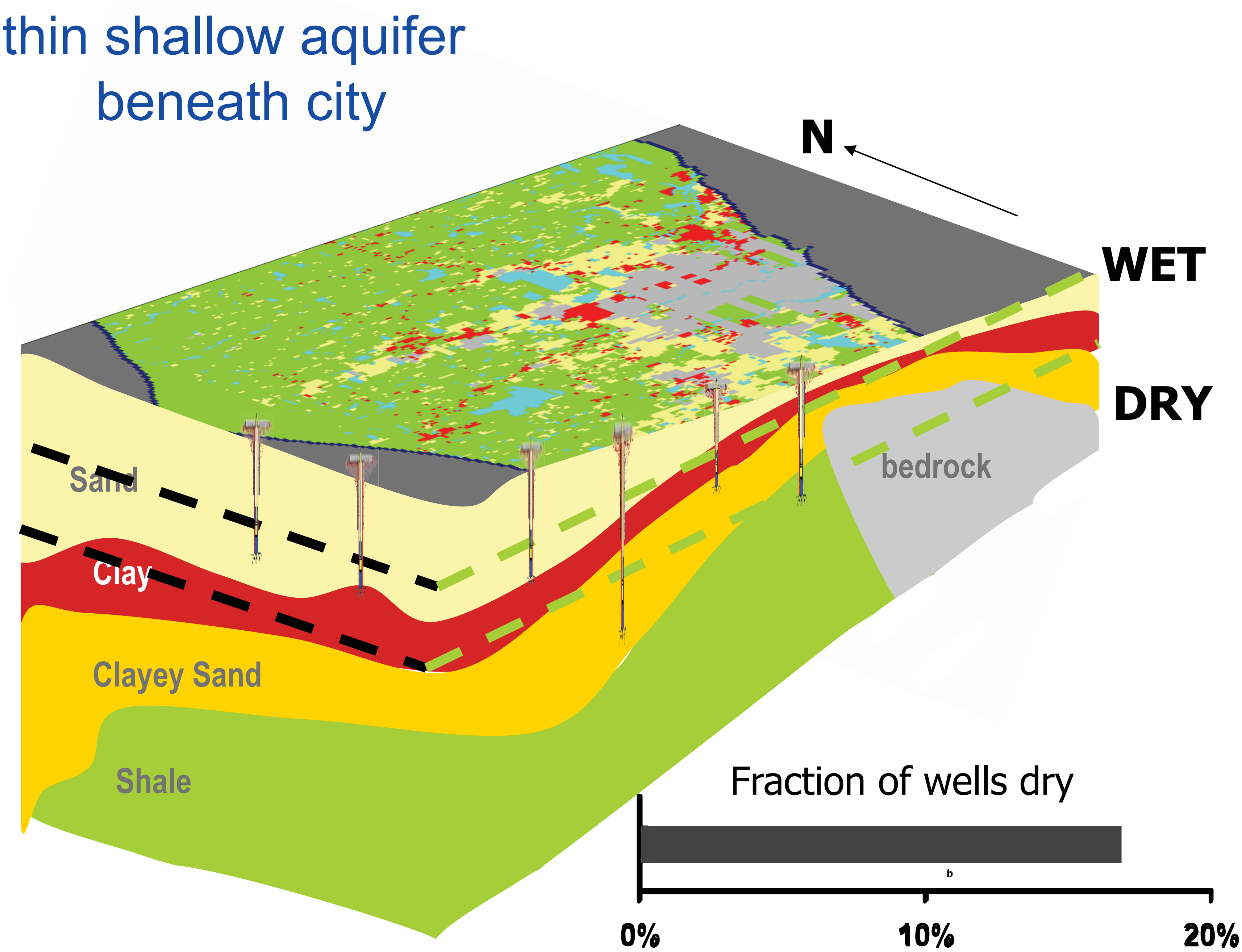


Groundwater module

Purpose: To estimate the number of wells that go dry.

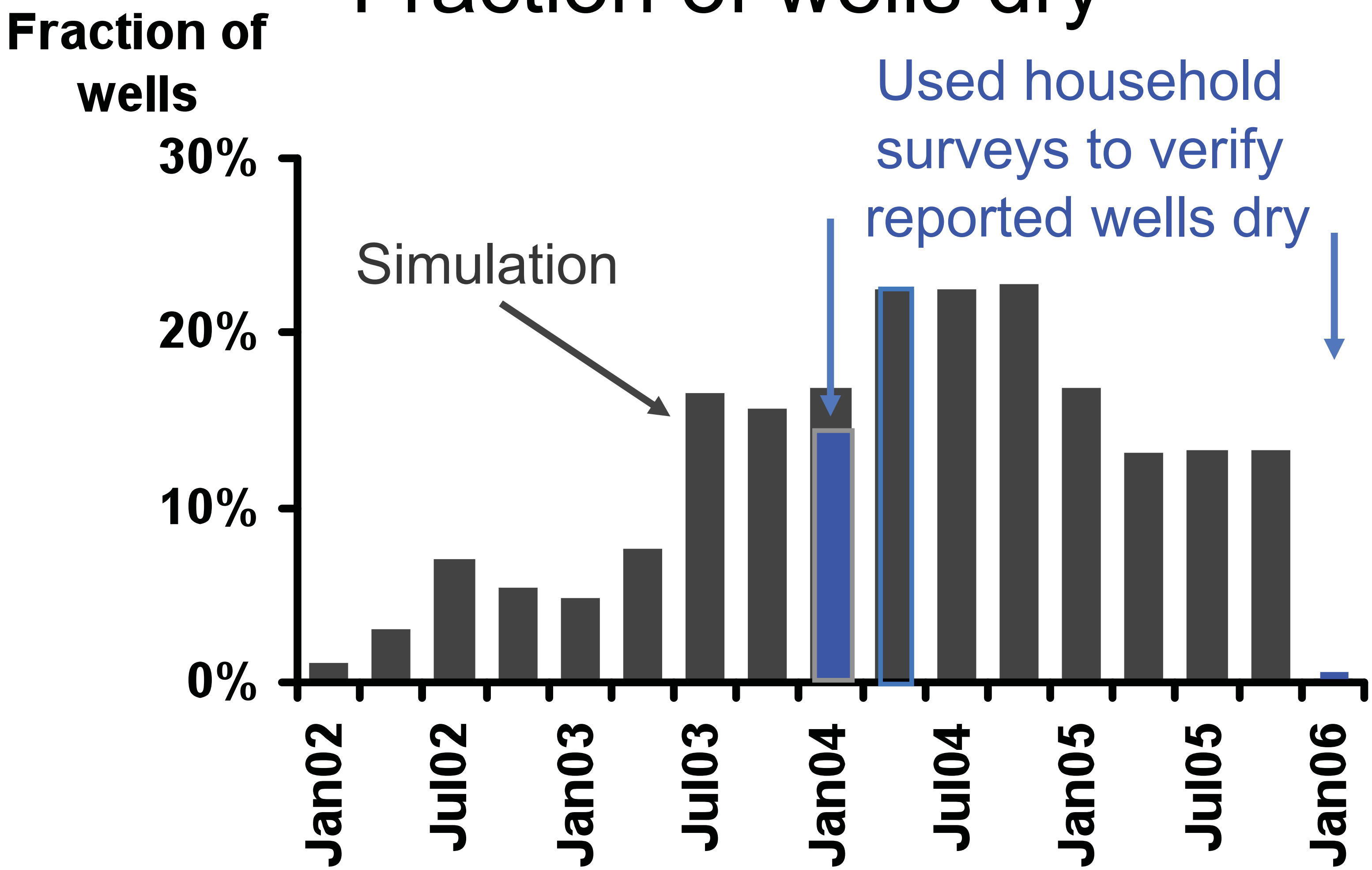


- Landsat 5 images
- 30 m resolution
- Manual and automated land-use classification



thin shallow aquifer
beneath city
N
WET
DRY
Sand
Clay
Clayey Sand
Shale
bedrock
Fraction of wells dry
0%
10%
20%

Fraction of wells dry



17-23% of Chennai's wells went dry during the drought.

After the record rains in 2005, groundwater levels recovered.

Water allocation-economic model used to “project” to 2025

Demographics – 1 million more people

- Population growth: 1.2% in city, 2.25% suburban
- Income: Real household income up 4% per year

Physical – conversion of agricultural to urban land

- Land use: Clark Urban Growth Model
- Climate: 1988-2005 historical rainfall for 2006-2025

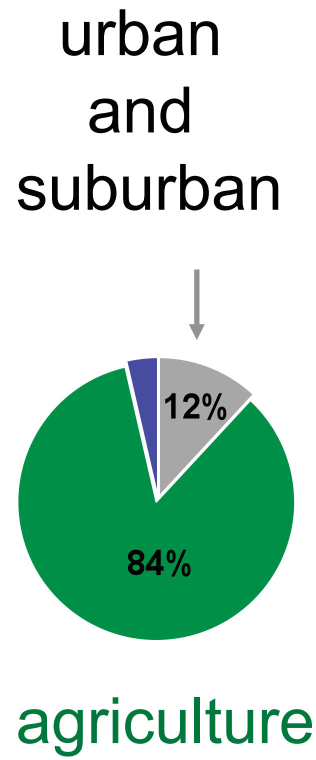
Investments – augment supply by 1/8

- Utility: 100 MLD Desalination plant in 2009

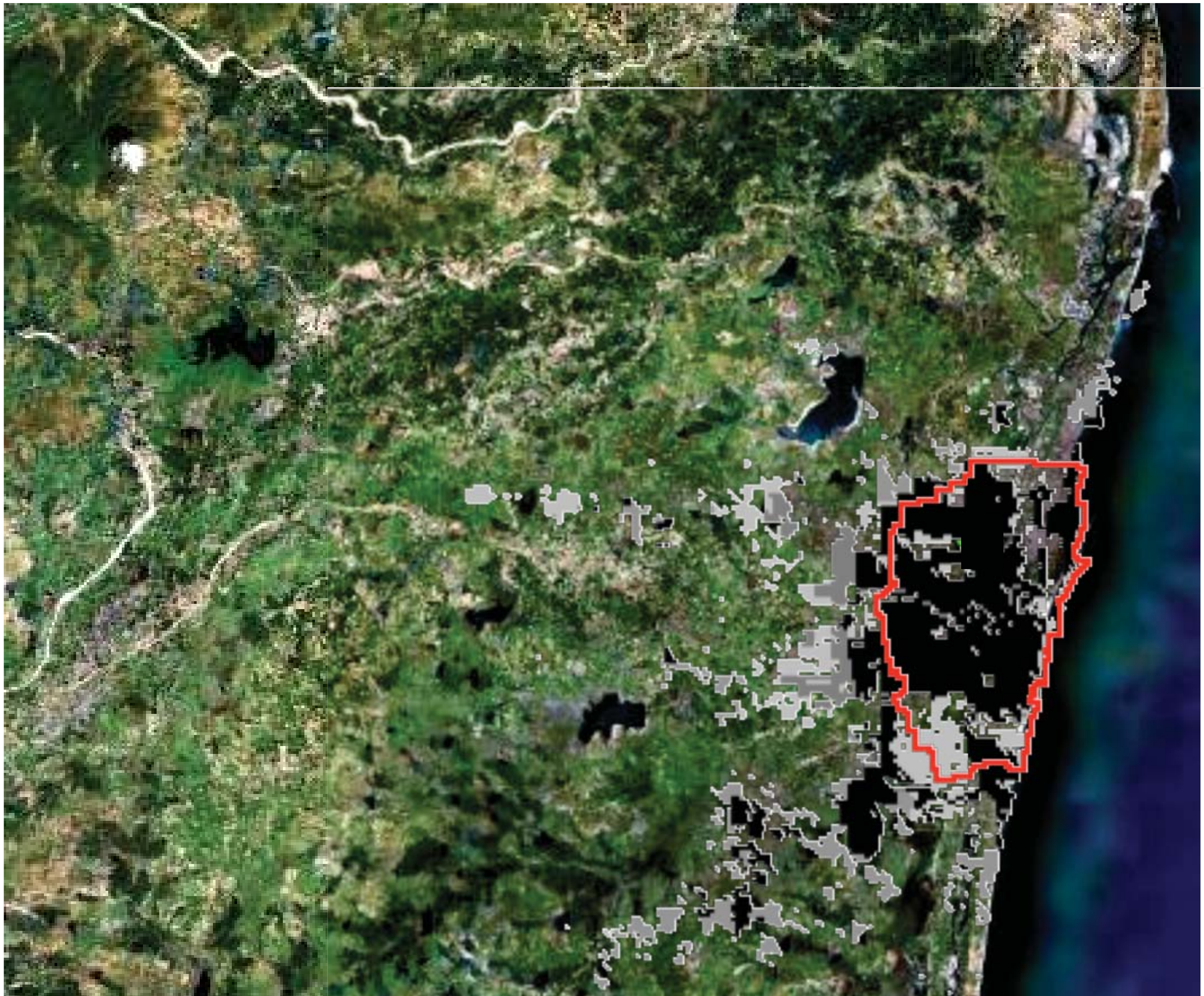
Prices – inflation adjusted

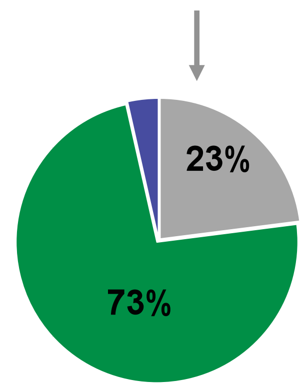
- Prices: Real prices constant over time

Chennai land-use map: 1988

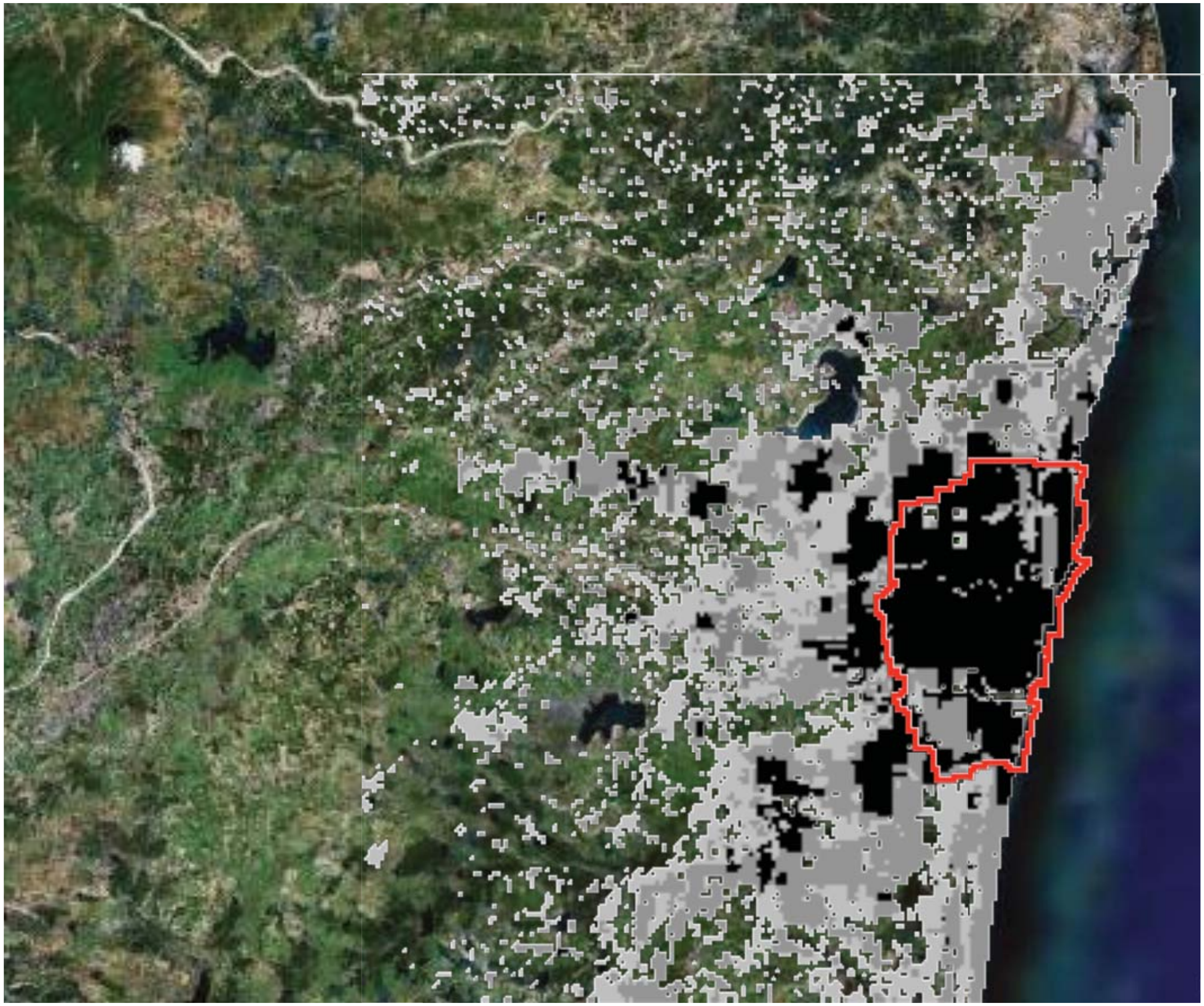


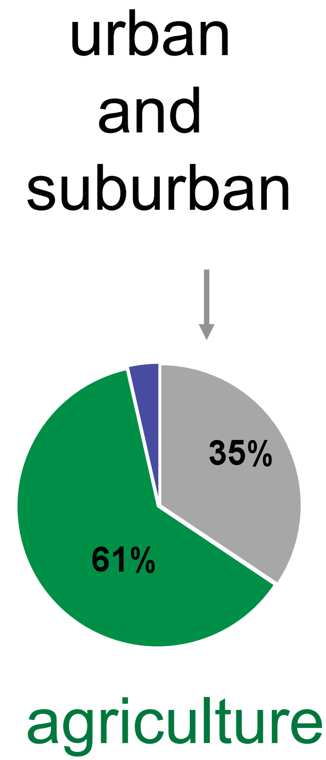
Chennai land-use map: 2000



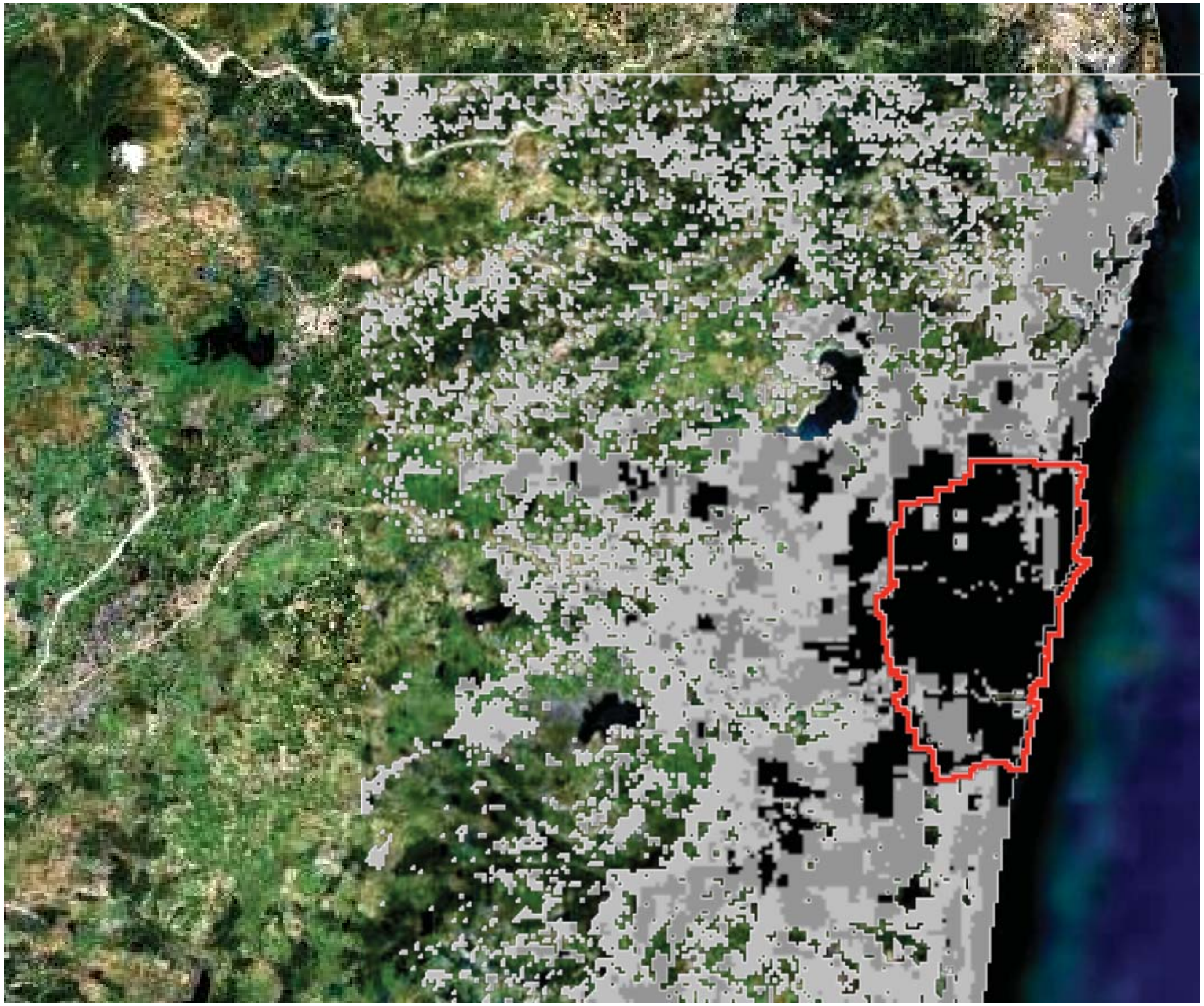


Chennai land-use map: 2010

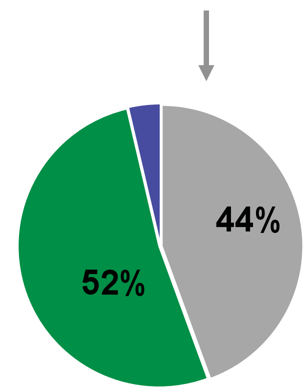




Chennai land-use map: 2015

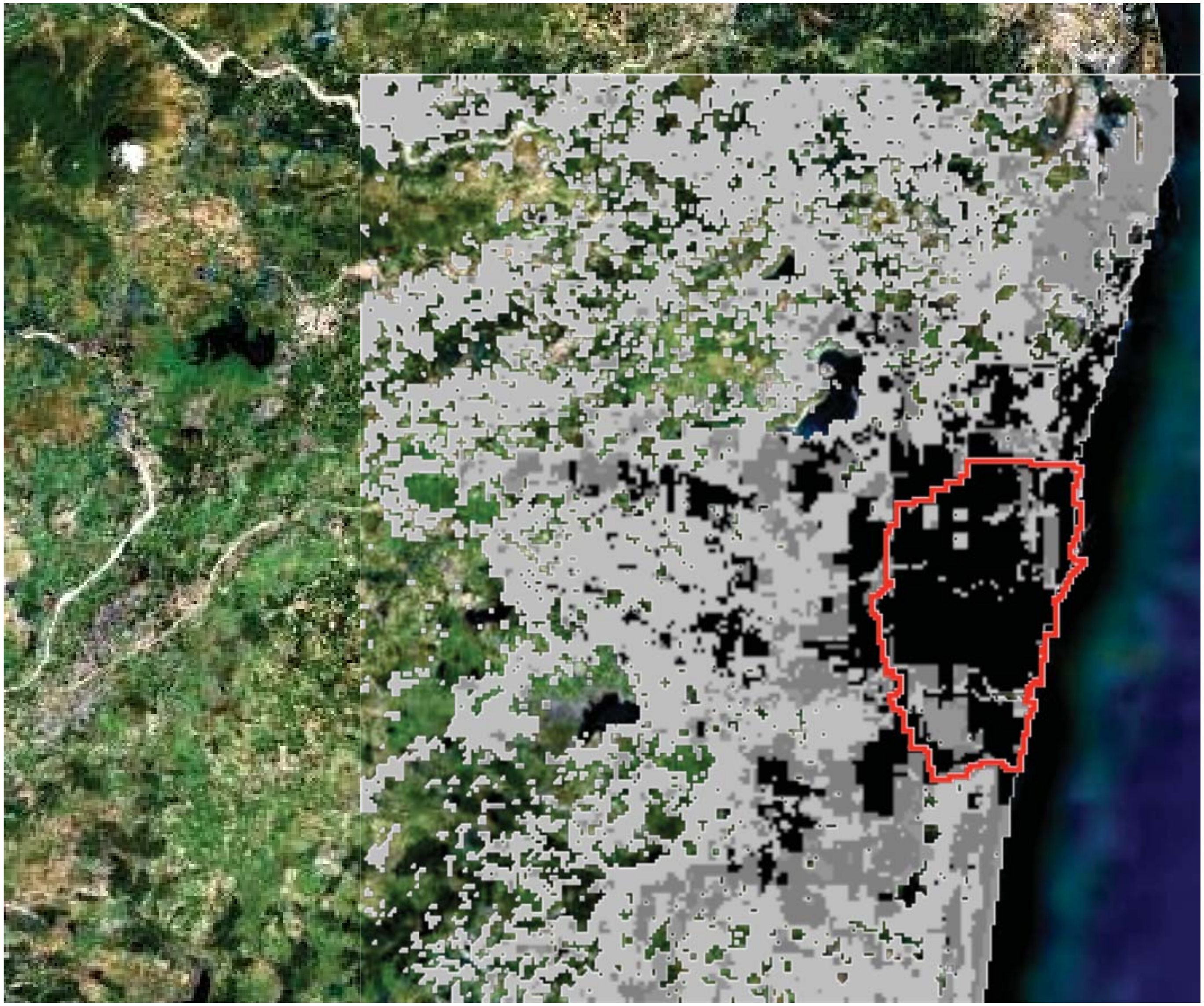


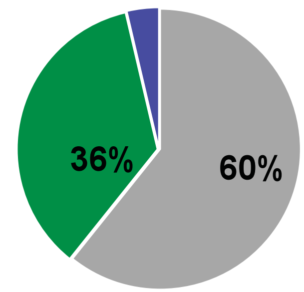
urban
and
suburban



agriculture

Chennai land-use map: 2025



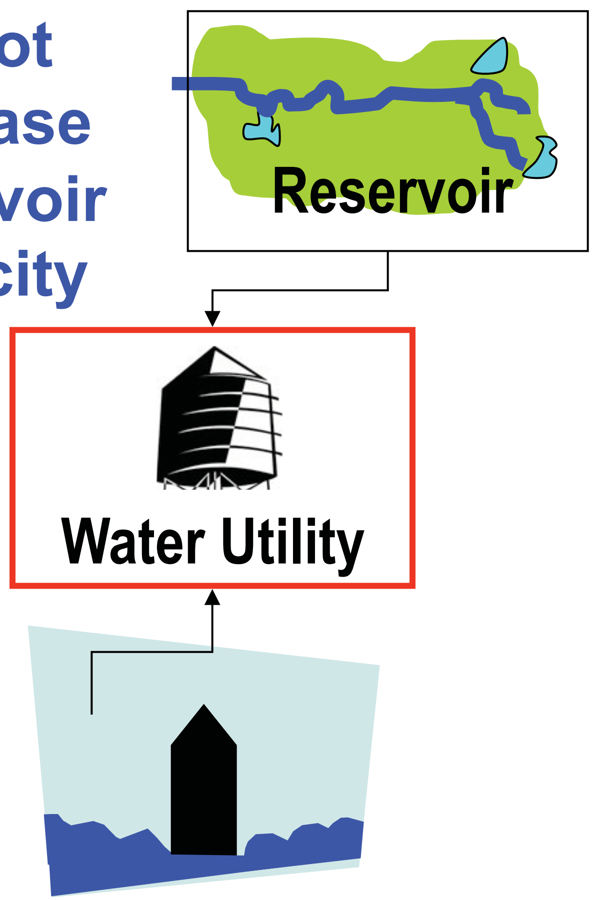


forecast using Clark urban growth model

Utility-based solutions

Add Supply

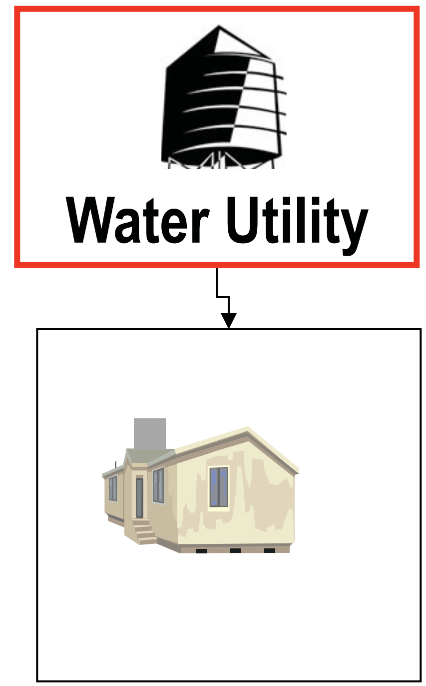
Cannot increase reservoir capacity



Second desalination plant

Improve Efficiency

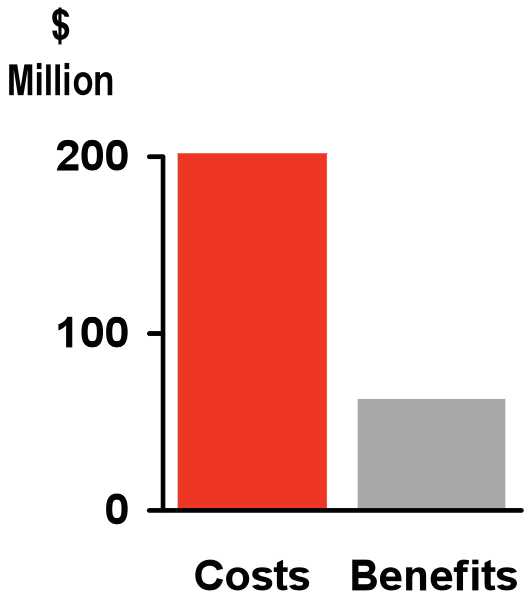
Reduce pipeline leakage from 25% to 12%



~ Double water price for wealthy consumers

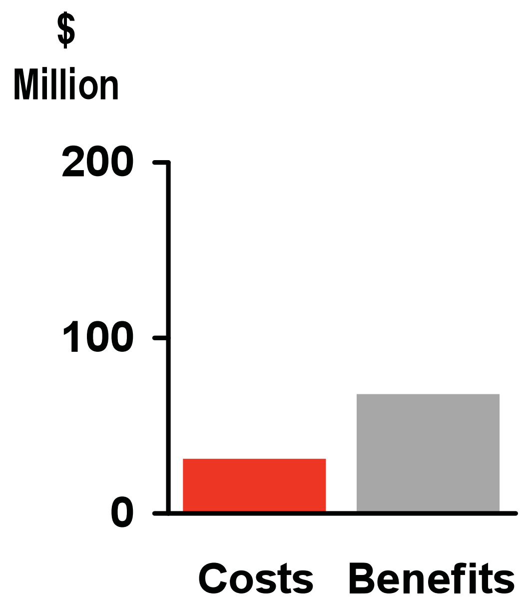
Economic Comparison of Policy Scenarios

Supply Augmentation



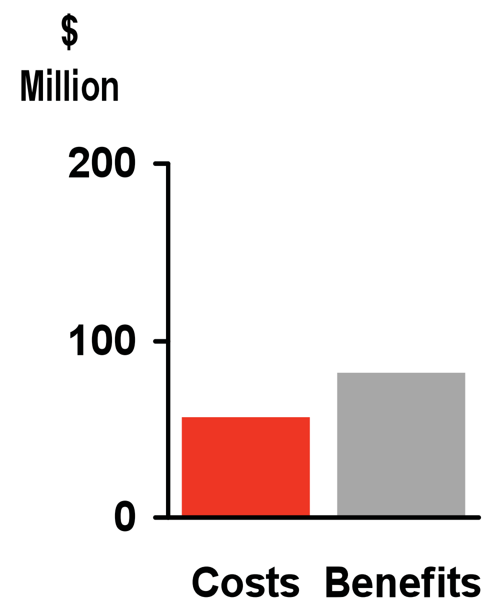
Cost: $1 per kL

Efficiency Improvement



Cost: $150 per Connection

Rainwater Harvesting



Cost: $120 per Household

Comparison of three solutions

	Add Supply	Improve Efficiency	Harvest Rainwater
Prevents total shut-down of piped system	✓	✓	
Provides drought relief by storing groundwater			✓
Revenue to utility	✓	✓	
Benefit to cost ratio > 1		✓	✓

Combined solution can replace expensive desal

Efficiency plus Rainwater Harvesting

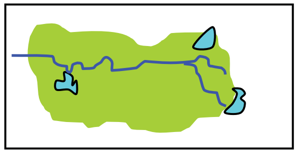
Raise price on richest consumers

Reduce leakage in piped supply

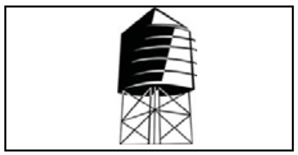
Use harvested groundwater for non-potable supply

No need for a second desal plant

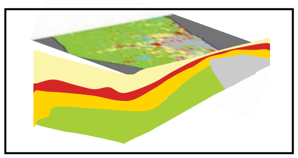
Combined Efficiency-Harvesting Strategy



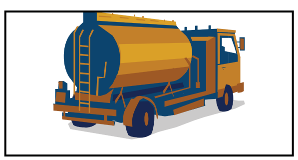
Reservoir still goes dry for extended period



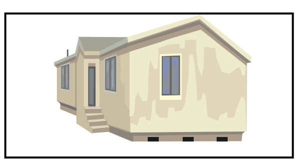
Piped supply does not shut down during drought



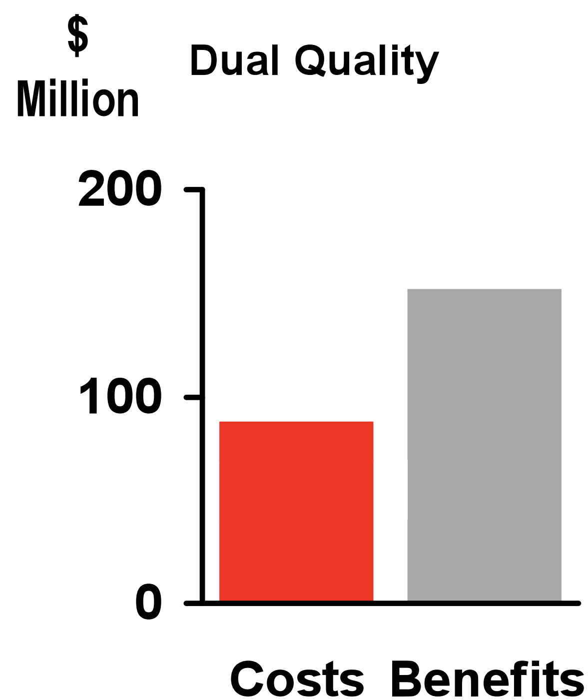
Rainwater harvesting limits drawdown : 75% fewer dry wells



Tanker market is only 10% of the base case



Consumers benefit from recharge and lower pipeline losses



Lessons learned
(from our studies)

Developing regions are on the vulnerable edge of necessary water supply. (limited memory)

Central water managers have been ineffective.

Hydrologic-economic models enable water policy evaluation → better management.

Interdisciplinary training and research = problem solvers

Global Freshwater Initiative

Objective: To find strategies for long-term freshwater provision to people and ecosystems threatened by global change.

- **Solution-oriented academic research**
- **Global in scope but regional in focus**
- **Multiple drivers of vulnerability**

Scales and Hydrologic Impacts

Time: 10 to 30 years

Space: watershed to multi-watershed

Impacts: 1) <u>frequency, timing, magnitude</u> of water availability
2) rapid <u>change</u> in water availability, quality, and use

Drivers

The collective interactions of forces controlling the vulnerability of water resource systems in different regions of the world.

NATURAL RESOURCE DRIVERS

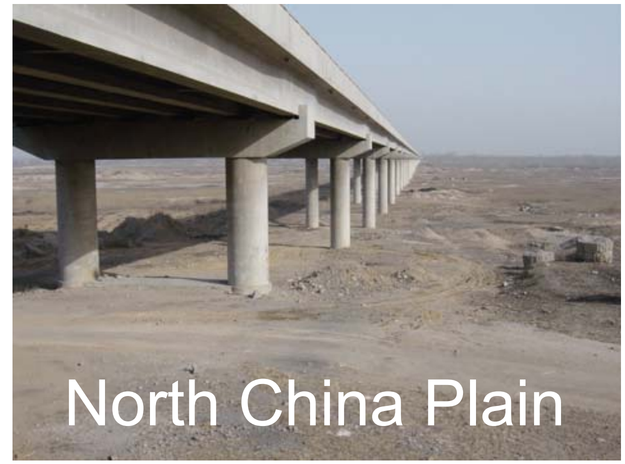
- **Climate** (temperature & consumption)
- **Water Availability** (precipitation/runoff)
- **Land Cover** (deforestation, ag to urban)

ENGINEERED RESOURCE DRIVERS

- **Infrastructure** (dams, transfer schemes)
- **Technology** (pump efficiency, desal)

HUMAN RESOURCE DRIVERS

- **Population** (migration, urbanization)
- **Economy** (inflation, industrialization)
- **Institutions** (regulations, environmental needs, trade barriers)


North China Plain


Disappearing Rivers

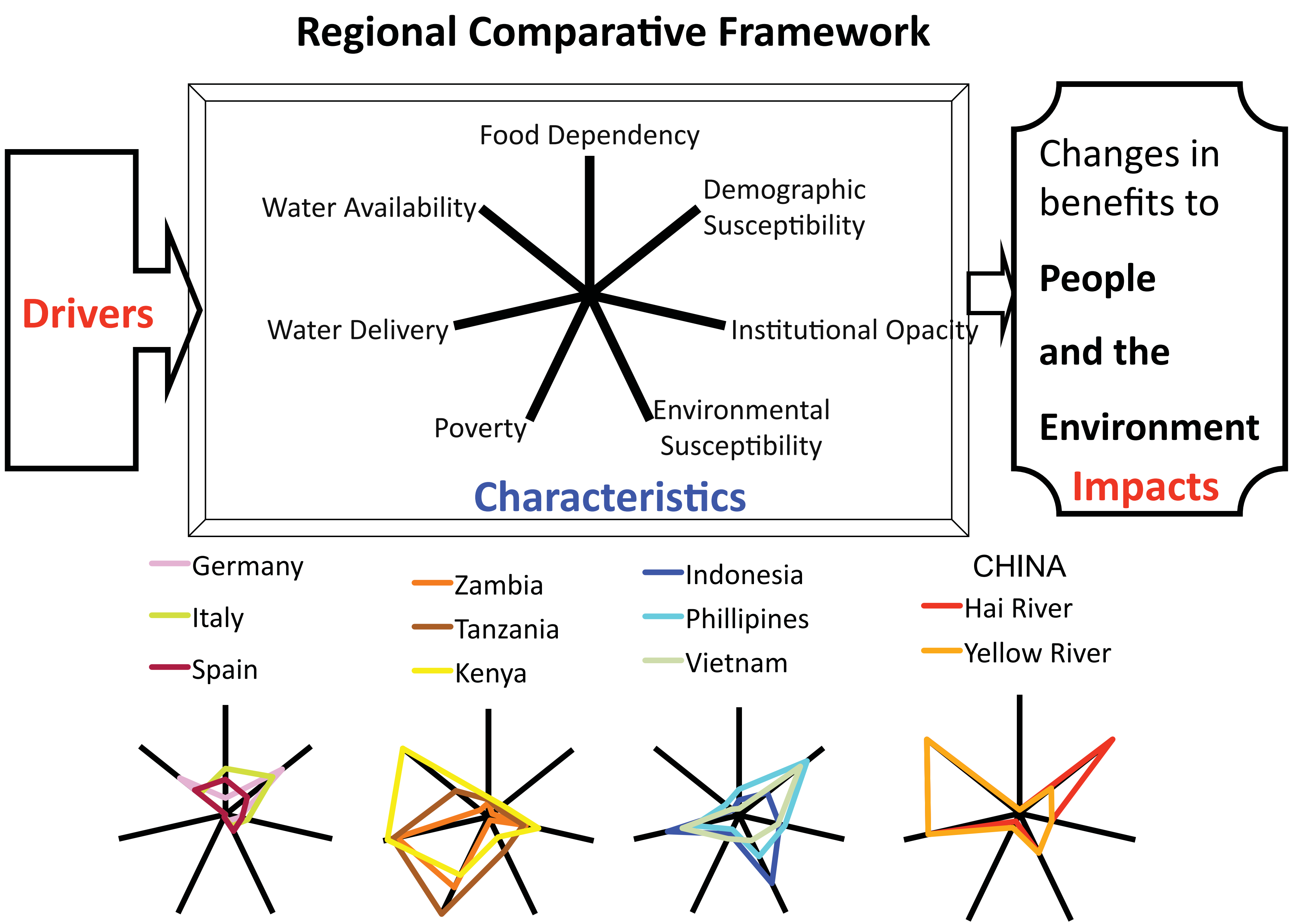
Regional Comparative Framework

Drivers

NATURAL RESOURCE DRIVERS

ENGINEERED RESOURCE DRIVERS

HUMAN RESOURCE DRIVERS


Regional Comparative Framework
Drivers
Food Dependency
Water Availability
Demographic Susceptibility
Water Delivery
Institutional Opacity
Poverty
Environmental Susceptibility
Characteristics
Changes in benefits to
People
and the
Environment
Impacts
Germany
Italy
Spain
Zambia
Tanzania
Kenya
Indonesia
Phillipines
Vietnam
CHINA
Hai River
Yellow River

Modular Modeling Framework

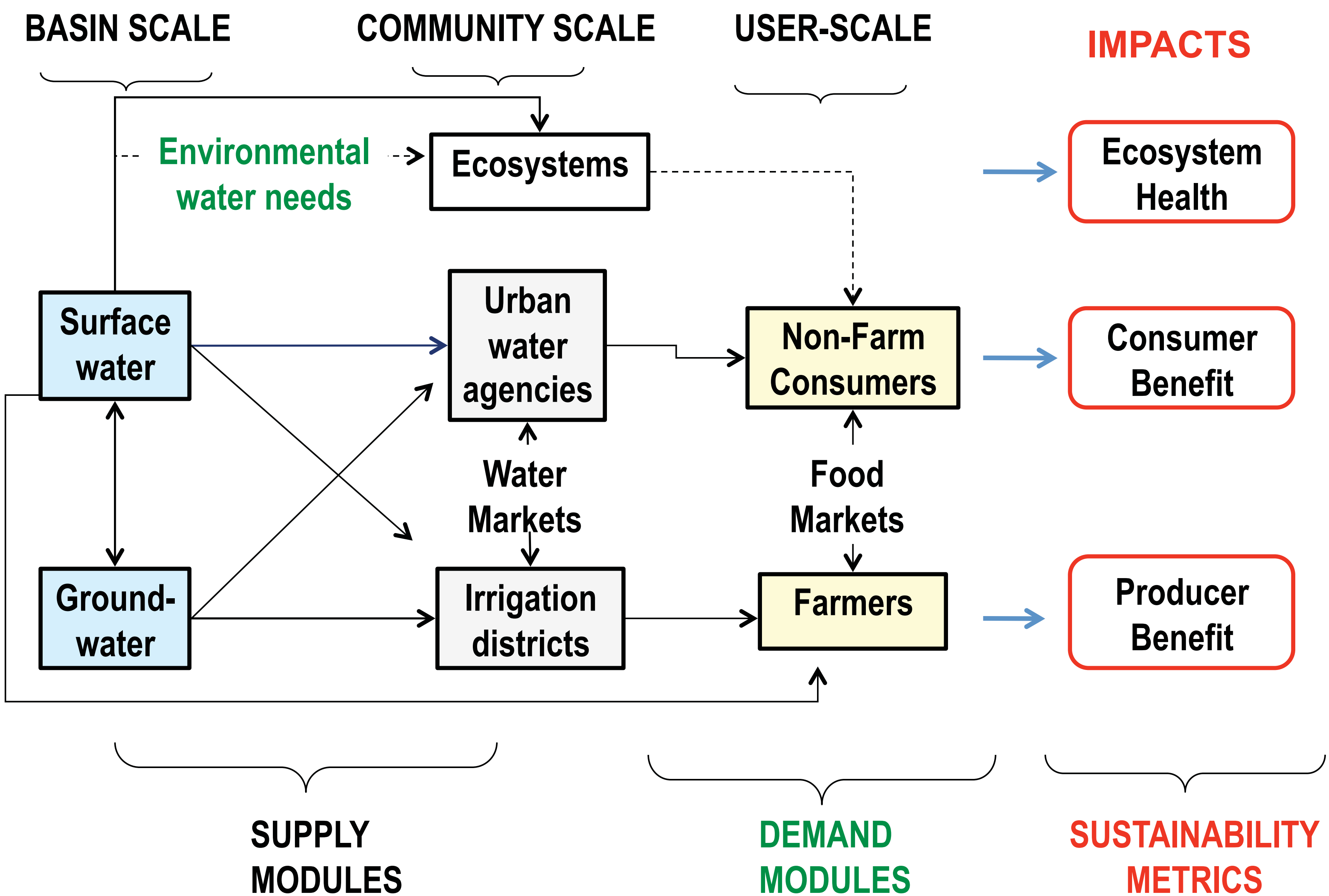
We don’t have predictive models that cut across disciplines.

To understand which policies will work, we need integrated models of hydrology and economics.

Reservoir Mismanagement

Rainwater Harvesting

Modular Regional Investigation Model



GFI Proposed Activities

Regional Investigations

Group Model Building

Global Trade Model

Natural Experiments

North China Plain

Indo-Gangetic Plain

Western Australia

Eastern Arc Mts, Tanzania

Western US

- Uncommon Dialogs
- International Water Policy Forum

Products of the Global Freshwater Initiative

Understanding systems: a set of regional interdisciplinary policy evaluation models

Policy analysis: targeted appraisal of policy interventions for freshwater sustainability

Education: interdisciplinary training of the next generation of water resource experts

Global Freshwater Initiative Team

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Econ

Buzz Thompson
Law

Veena Srinivasan
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Eric Lambin
Geography

Larry Goulder
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Eco

Outside: Mike Hanneman (UC Berkeley, econ), Ignacio Rodriguez-Iturbe (Princeton, hydro) Claudia Pahl-Wostl (Osnabrück, modeler), Richard Howitt (UC Davis, econ)