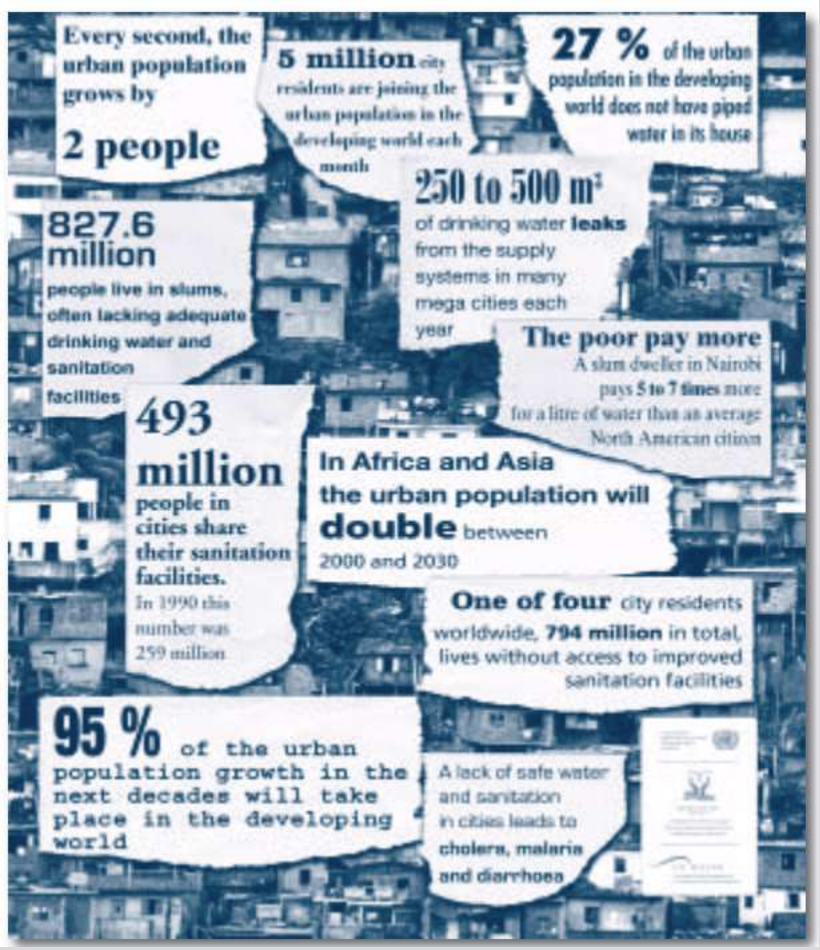
City-Source Interdependencies and Water Resilience: Mexico City and the Valley of Mexico

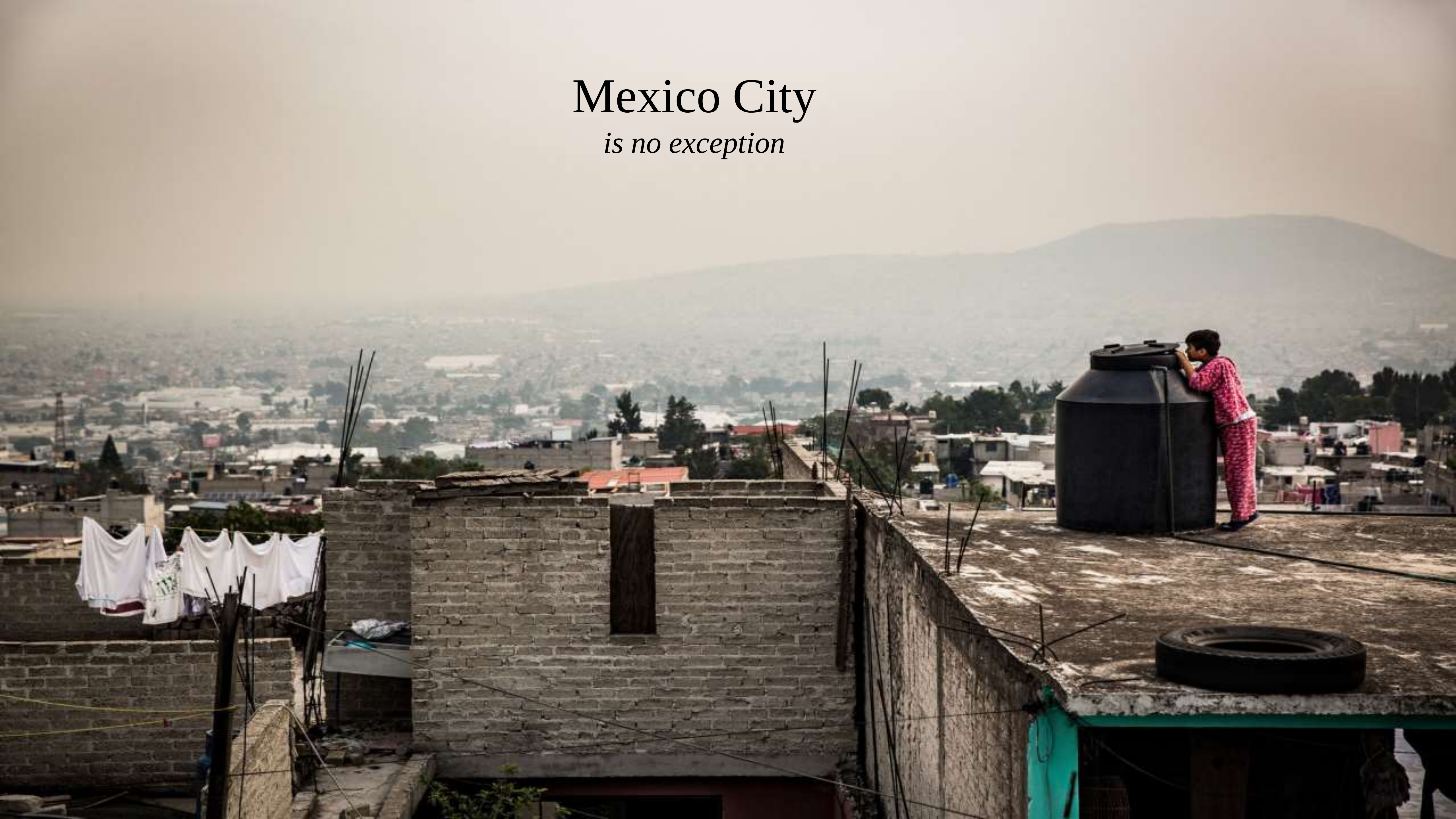
S. Freeman, C. Brown, A. Bruce, F. Gonzalez, R.G. Gonzalez, V. Martinez , P. Ray, D. Rodriguez, A. Romo, E. Vasquez, S. Wi



Water and urban growth by numbers

- Every second, the urban population grows by **2 people**.
- **95%** of the urban expansion in the next decades will take place in the developing world.
- In Africa and Asia, the urban population is expected to **double** between 2000 and 2030.
- Between 1998 and 2008, **1052 million** urban dwellers gained access to improved drinking water and **813 million** to improved sanitation. However, the urban population in that period grew by **1089 million** people and thus undermined the progress.
- **One out of four** city residents worldwide, 789 million in total, lives without access to improved sanitation facilities.
- **497 million** people in cities rely on shared sanitation. In 1990, this number was 249 million.
- **27%** of the urban dwellers in the developing world do not have access to piped water at home.

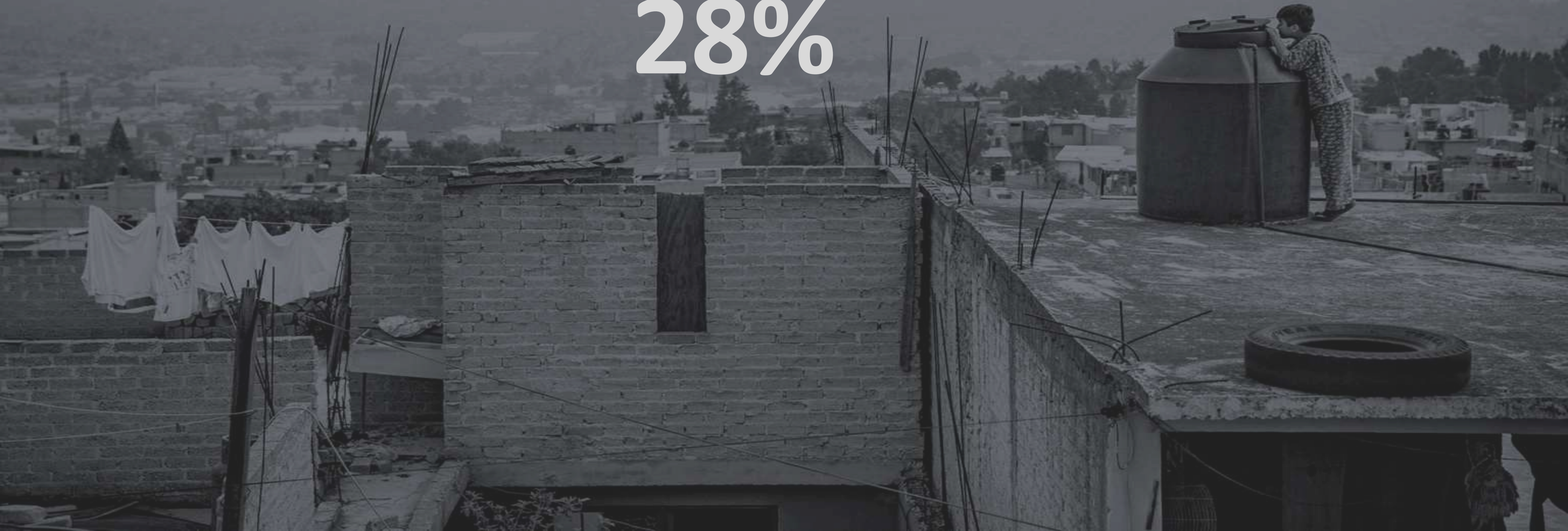
UN-Water Decade Programme on Advocacy and Communication (UNW-DPAC)


Mexico City
is no exception

The Current Situation

By 2025, the percent of Mexico City's population with access to acceptable quality of water service is projected to decrease from 82% to 28%.

28%



The Current Situation

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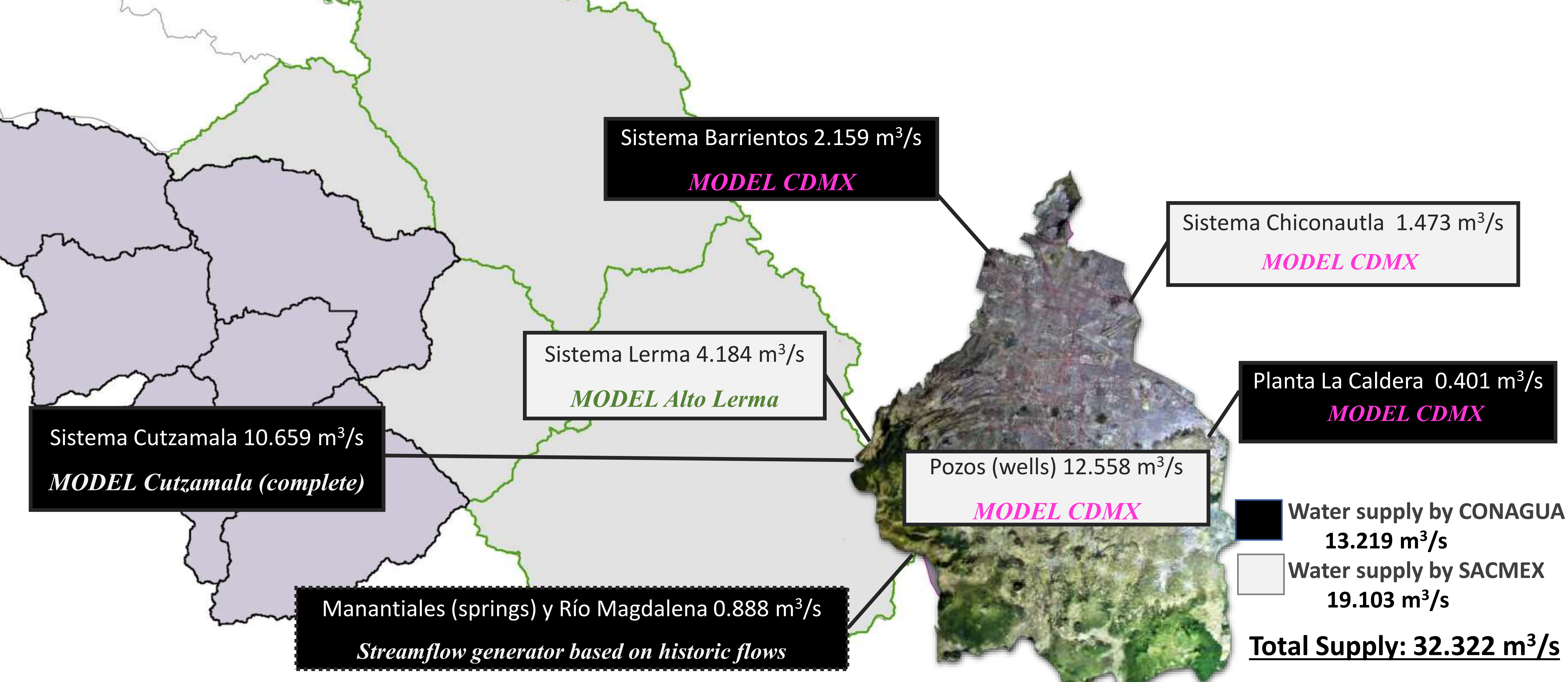
28%

- **Overexploitation of the aquifer** is currently estimated at **double** the recharge rate,
- **Subsidence** in the city ranges from **4 to 26 cm** per year, depending on part of city
- **Losses in the distribution system** are estimated to be **42%** of the total water supplied to the city (this includes water not accounted for, illegal capture and leakages).
- **Equity and inclusivity** are major issues; water scarcity and shortages are borne **disproportionately by the poor**.
- **Urban flooding and storm water management** are a **chronic** problem.
- The system is highly vulnerable to **earthquakes** and slow to recover .

Mexico City's Water

more to consider than just the city



Source: SACMEX

Mexico City’s Water

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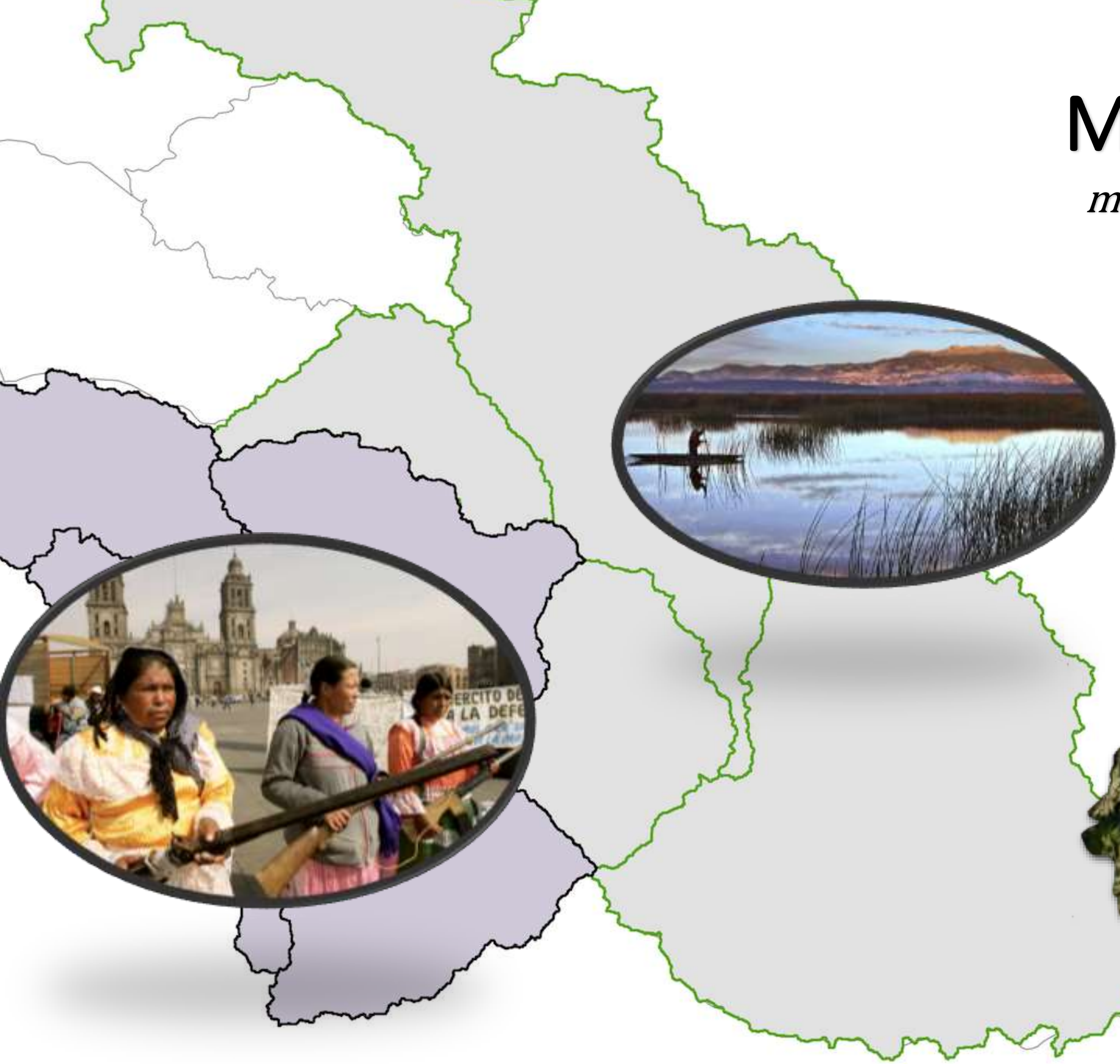

The New York Times | CLIMATE

Changing Climate, Changing Cities

Mexico City, Parched and Sinking, Faces a Water Crisis

Forbes México

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La mitad de la CDMX se inunda, la otra muere lentamente de sed

María Fernanda Navarro
Julio 27, 2017 @ 6:50 am

La Ciudad de México es incapaz de hacer frente a los problemas de manejo de agua, los que representan una paradoja: mientras una parte se inunda con una lluvia atípica, cada vez más colonias padecen escasez del líquido.

Climate change is threatening to push a crowded capital toward a breaking point.

By MICHAEL KIMMELMAN, Photographs by JOSH HANER

FEB. 17, 2017

Forbes México

ÚLTIMAS NOTICIAS SECCIONES LIFE LISTAS FORBES CA BRAND VOICE FORBES RD SUSC

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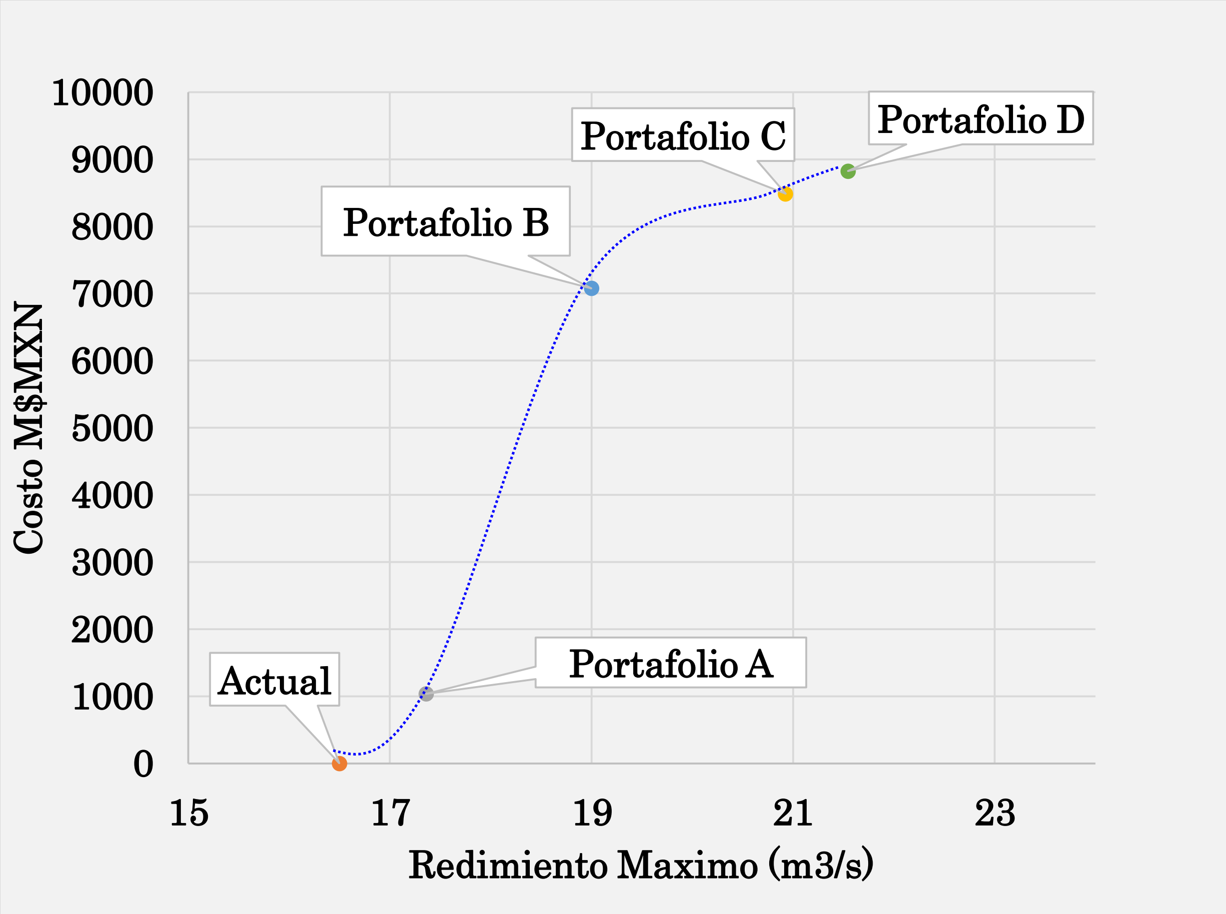
How do we design for resilience?

Traditional Water Resources Planning:

engineers determine solutions which minimize costs

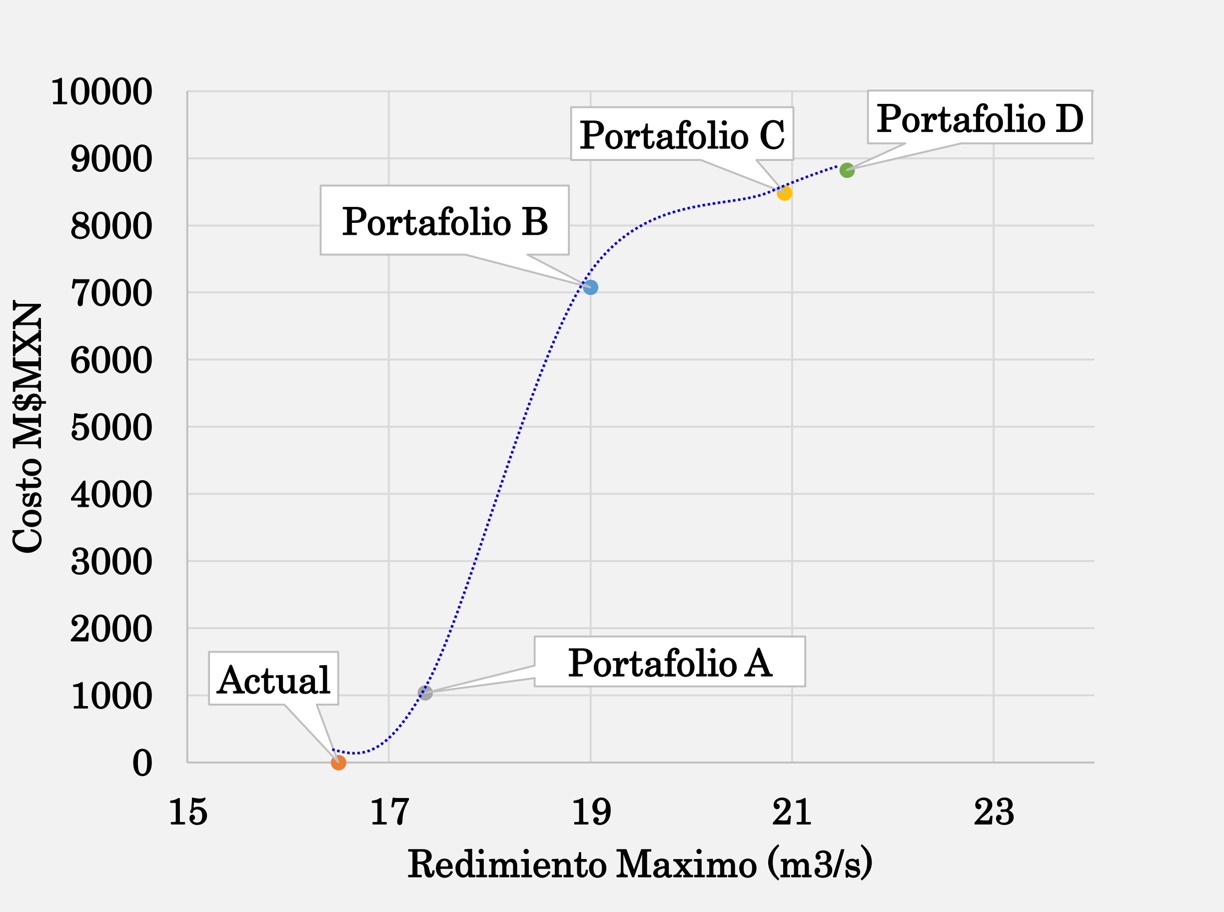


Traditional Water Resources Planning:

engineers determine solutions which minimize costs

However…

- What happens when shocks happen?
- Climate change?
- Social equity?
- The environment?



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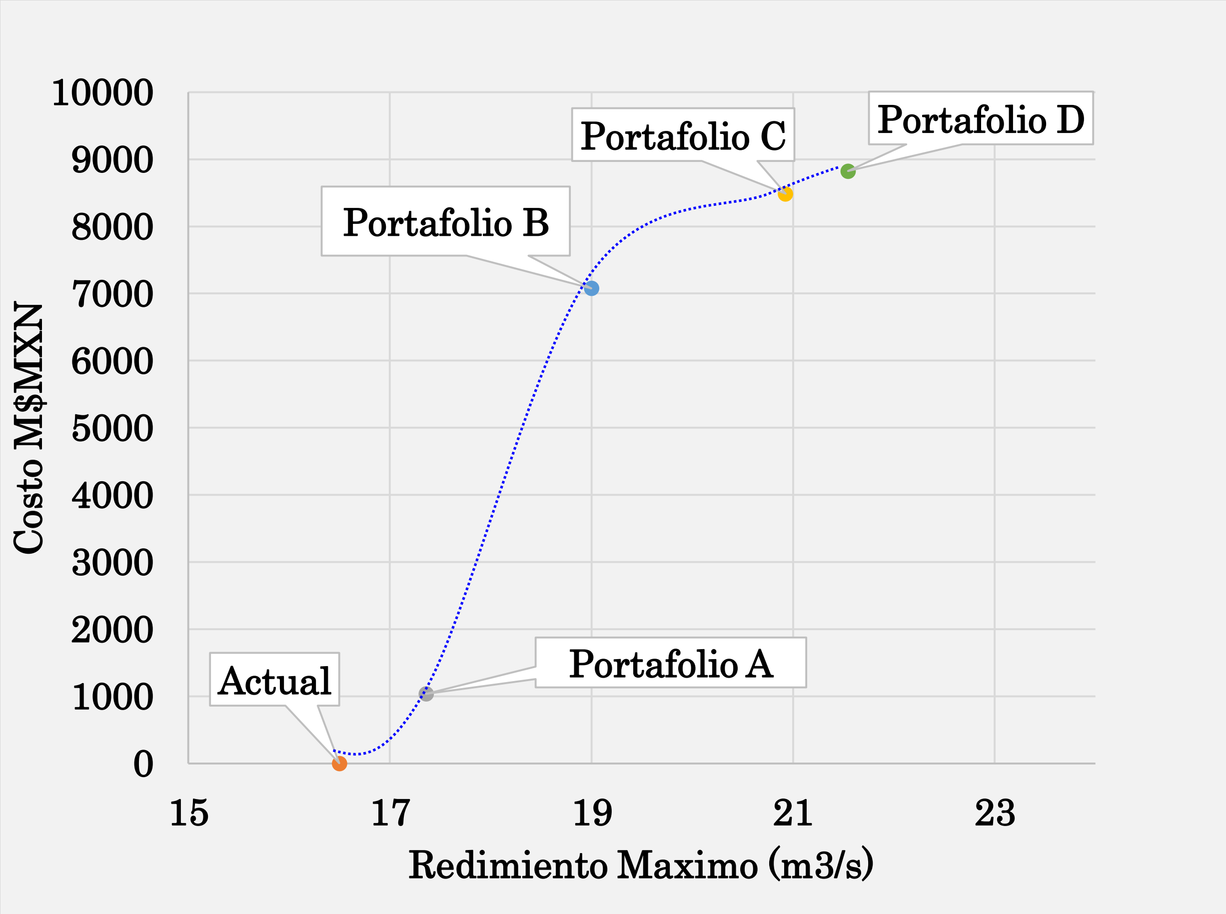

Traditional planning leads to fragile solutions.

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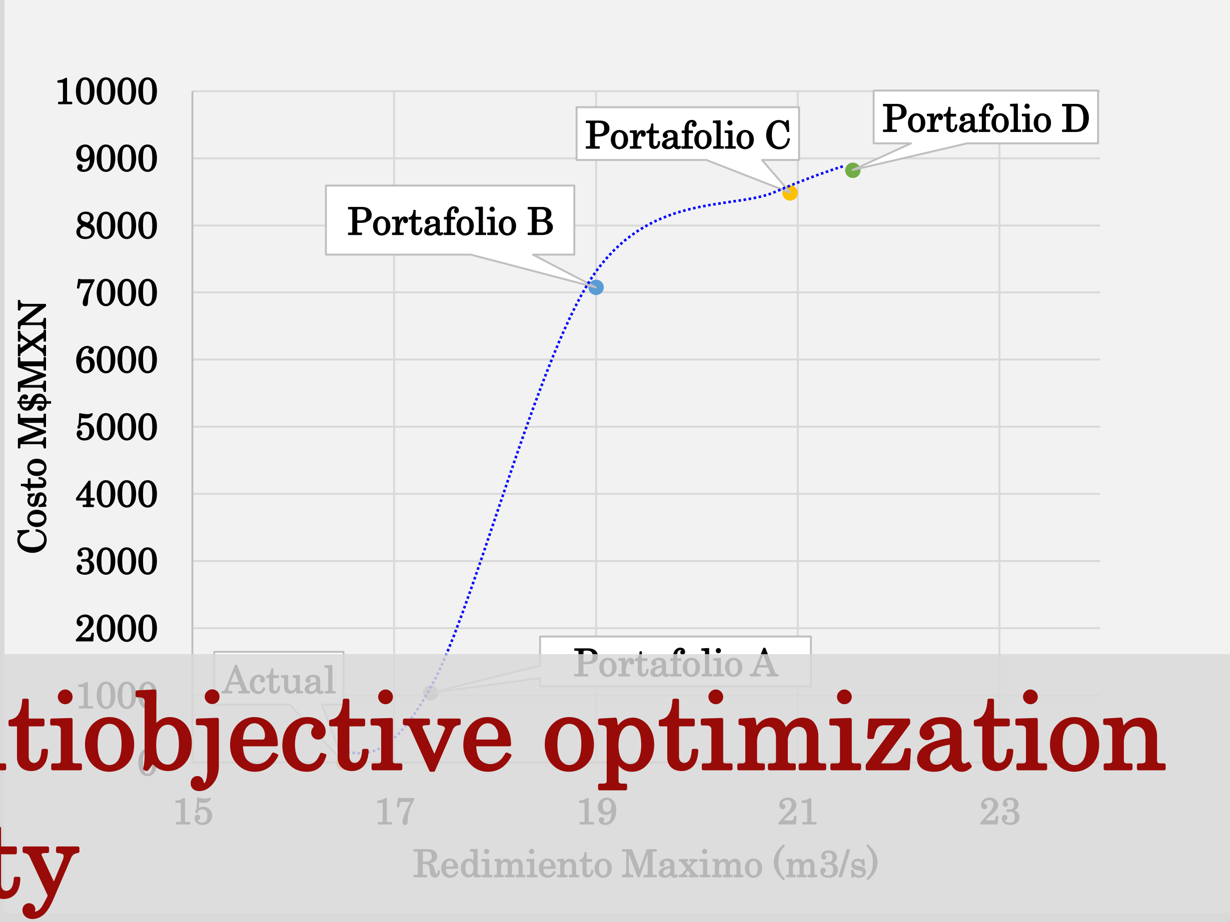

Robust stochastic multiobjective optimization under deep uncertainty

~~Traditional planning leads to fragile solutions.~~

Traditional Water Resources Planning:

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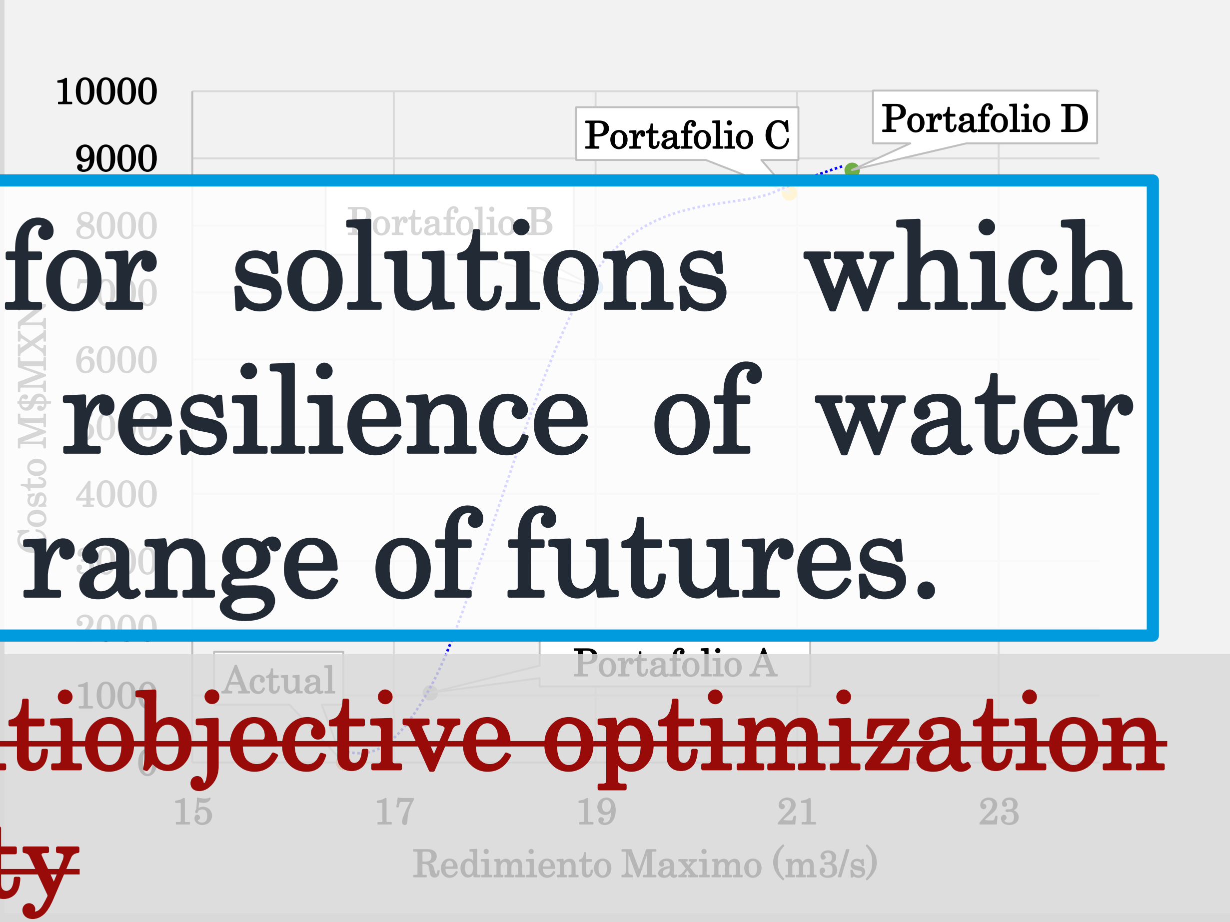


Systematic search for solutions which lead to the highest resilience of water services over a wide range of futures.

~~**Robust stochastic multiobjective optimization under deep uncertainty**~~

~~Traditional planning leads to fragile solutions.~~

Designing for Resilience

Measuring resilience

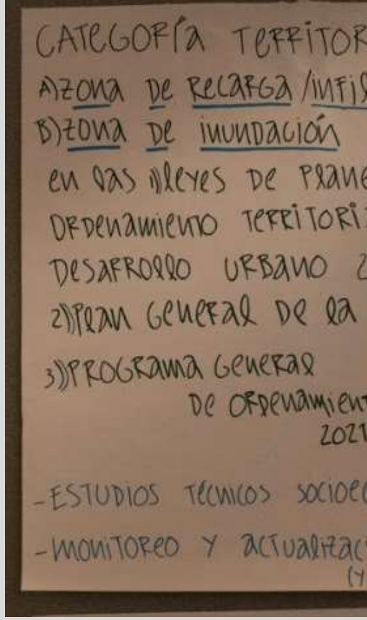
...a performance (and stakeholder) based approach.

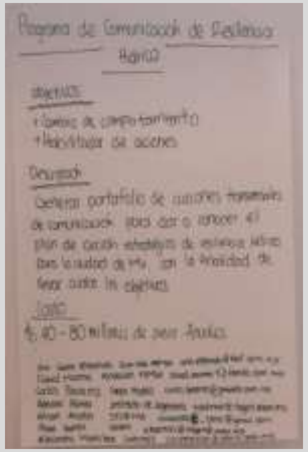
resilience

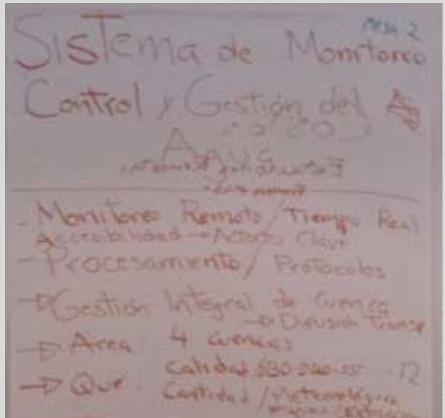
of what

to what

...and what can be done?

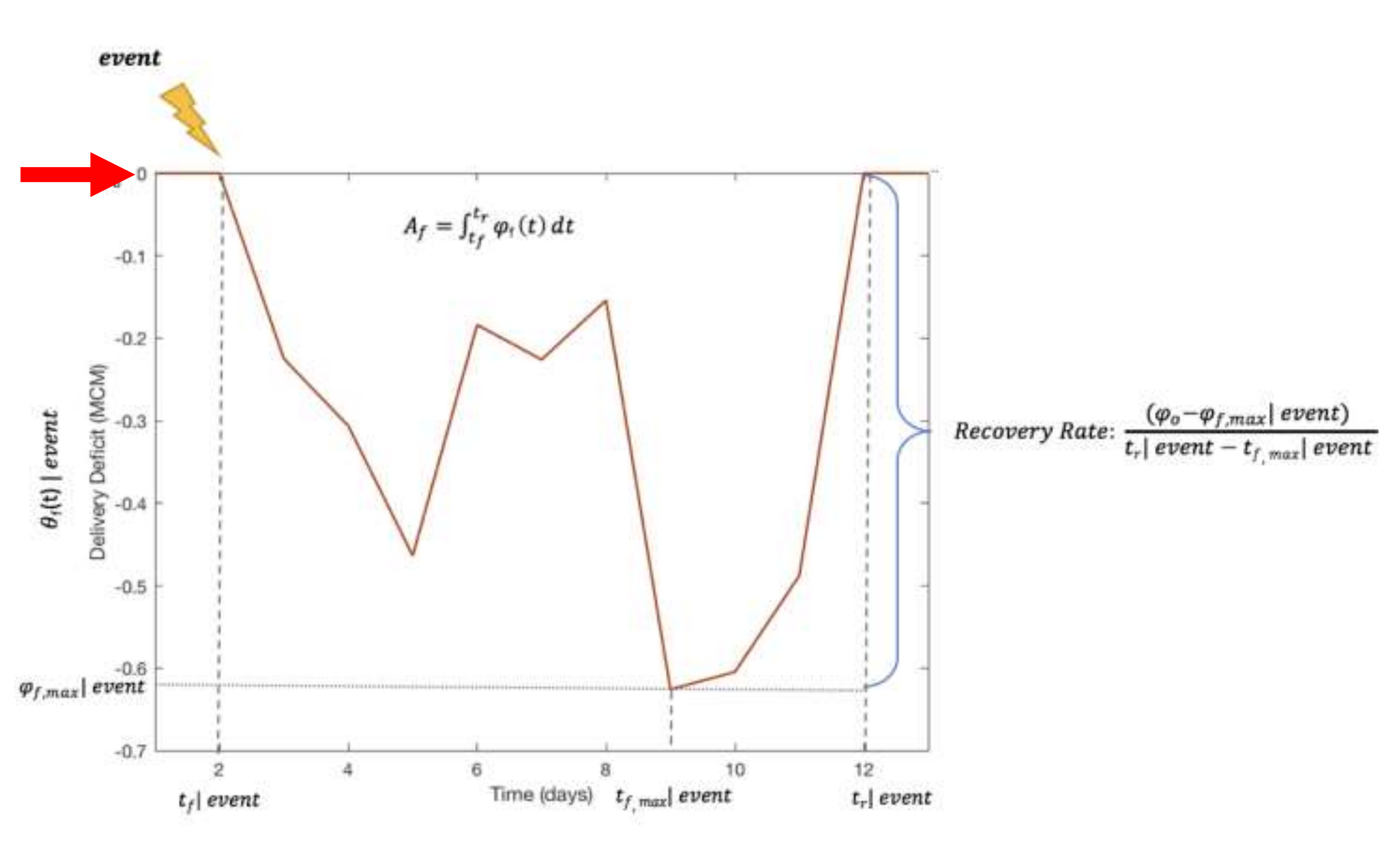






Measuring resilience | what is **resilience**

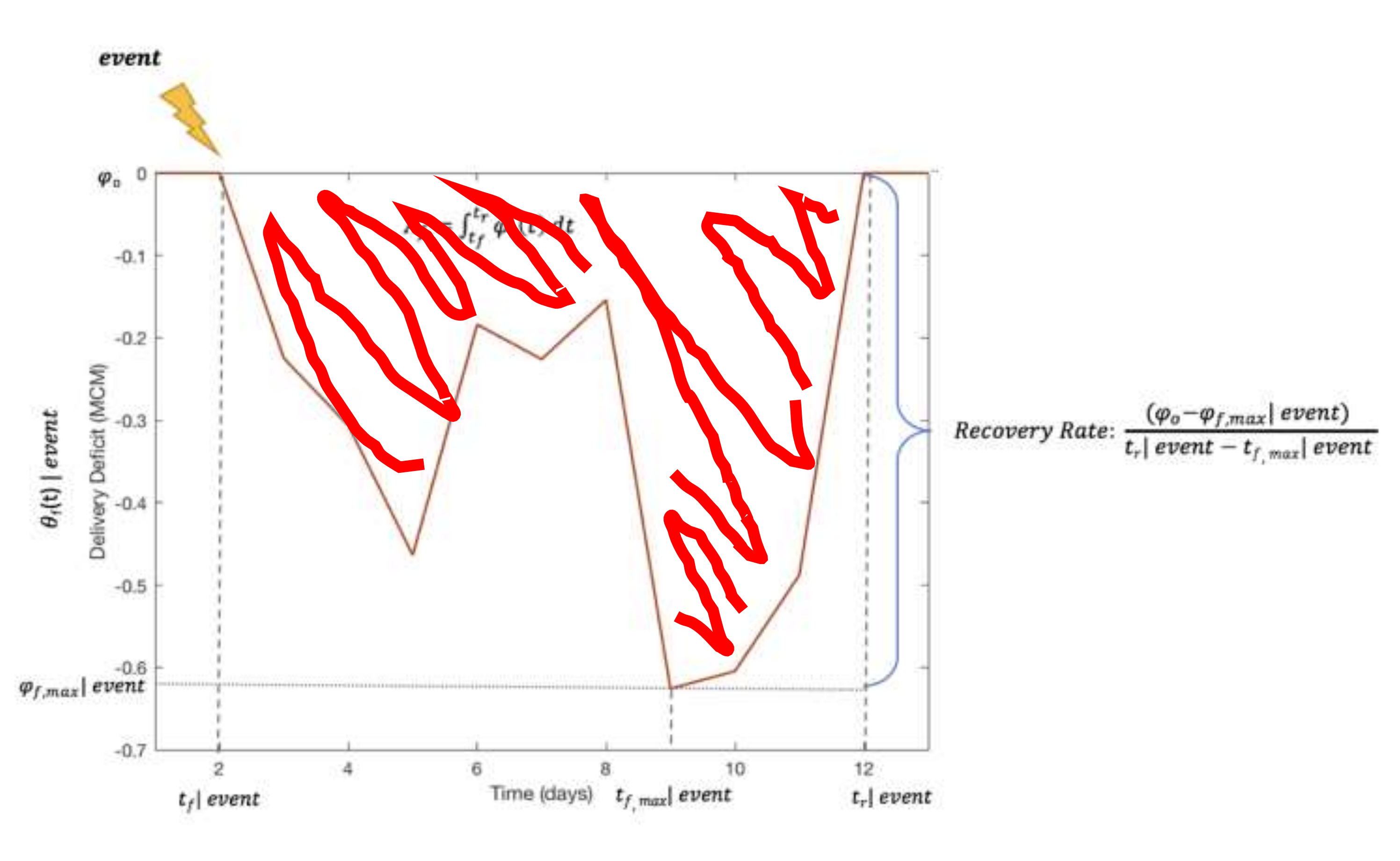
target performance level



Measuring resilience | what is resilience

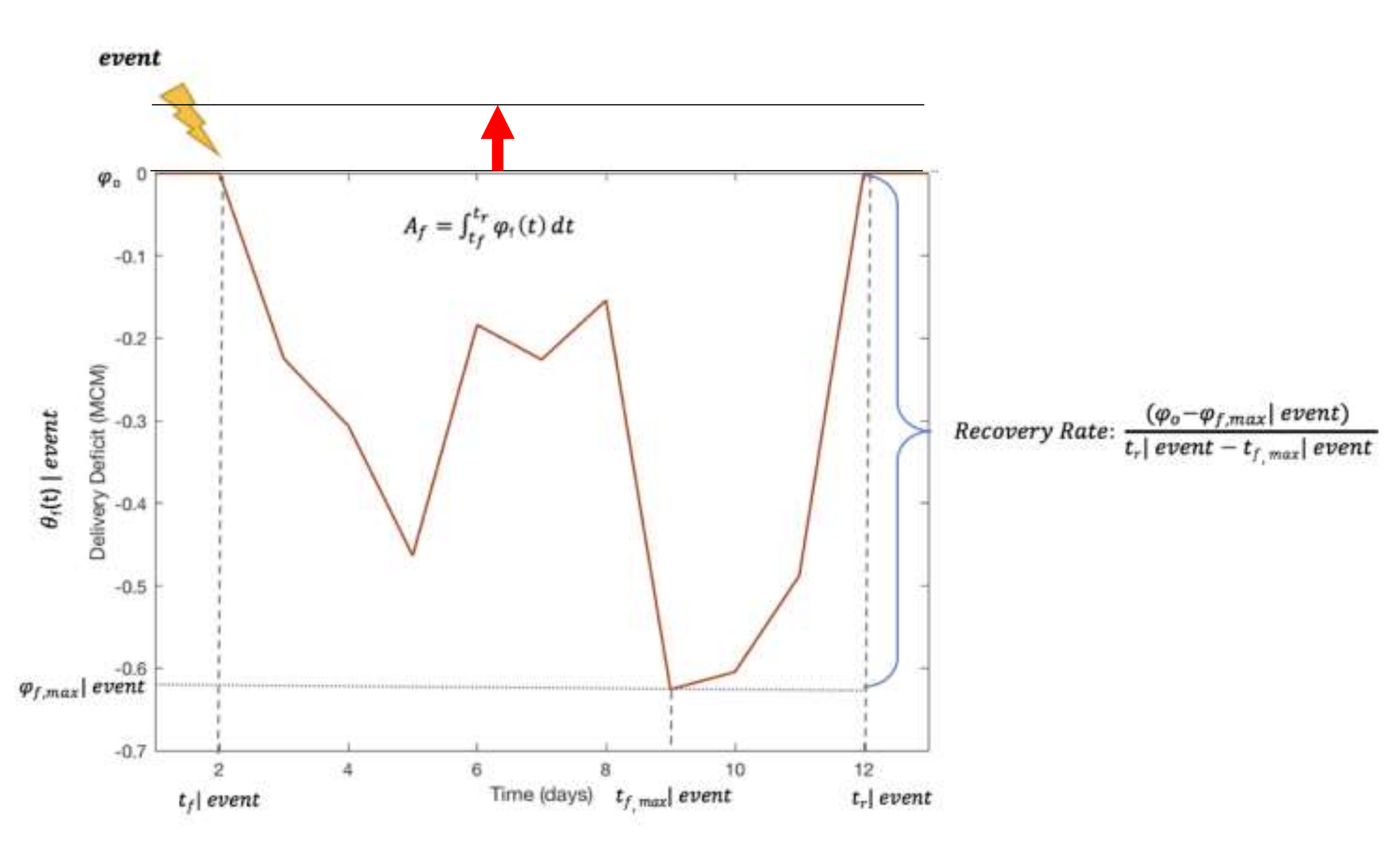
persistence: function and identity remain the same after disturbance

adaptability: function remains the same but identity changes after disturbance



Measuring resilience | what is **resilience**

transformability: function and identity change after disturbance (in a new acceptable steady state)



Measuring resilience | resilience of what

Cutzamala

Max Agricultural Delivery
Max equity of allocation
Max e-flow compliance

Lerma

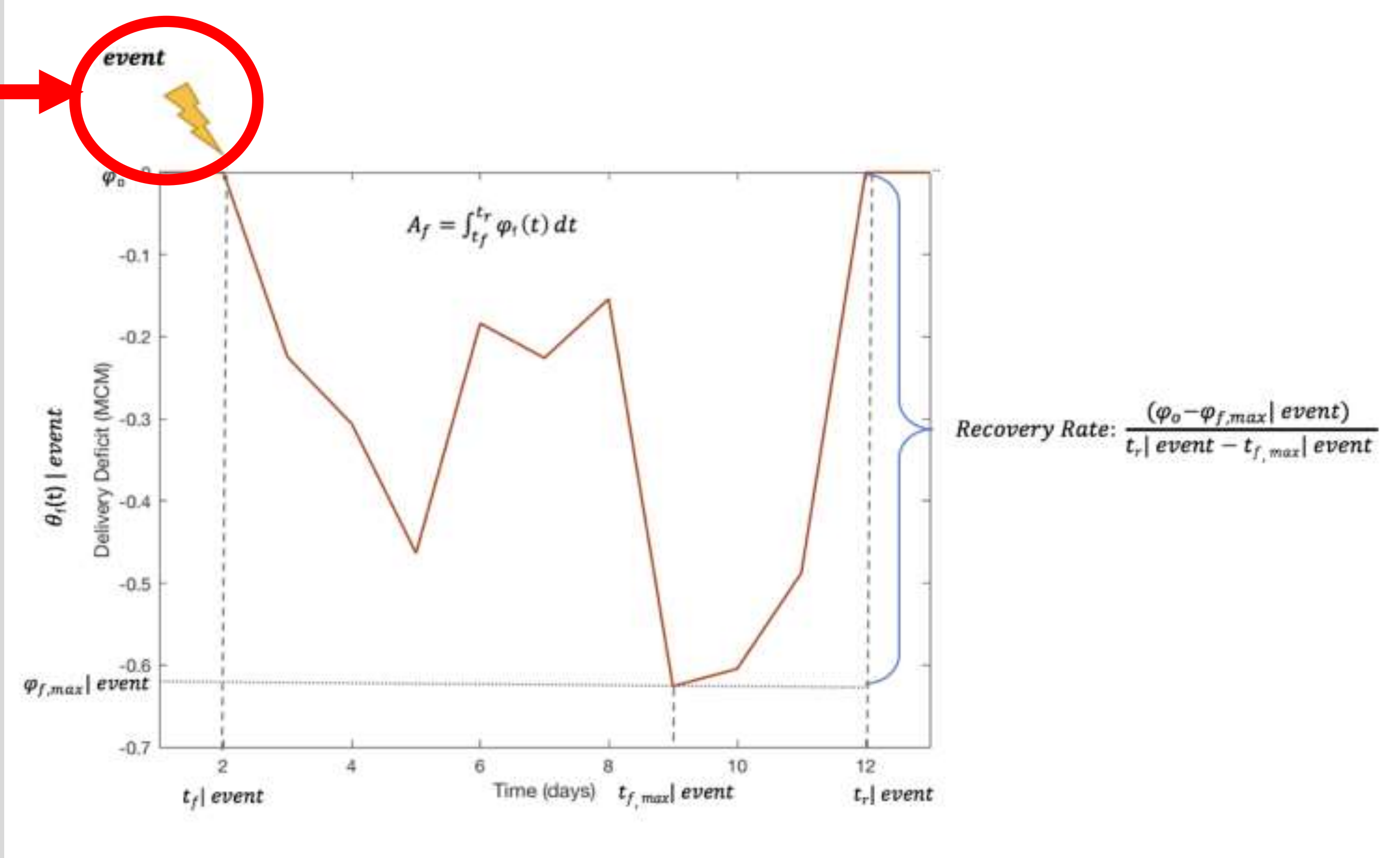
Max Municipal, Industrial & Agricultural Deliveries
Max Environmental Delivery (Cienegas de Toluca)
Max equity of allocation

CDMX

Max delivery at each delegation
Min aquifer depletion & subsidence
Max equity of allocation

Measuring resilience | resilience to what

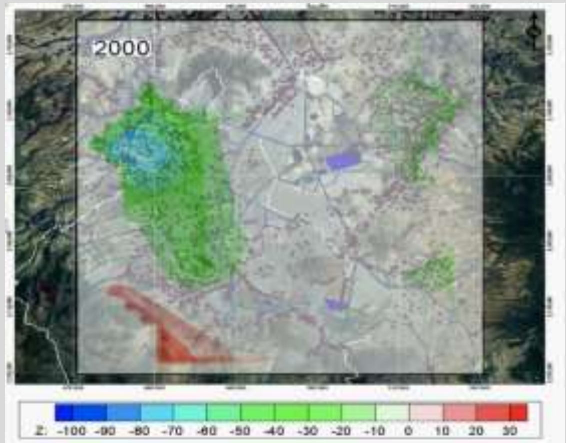
shocks,
stresses,
uncertainties

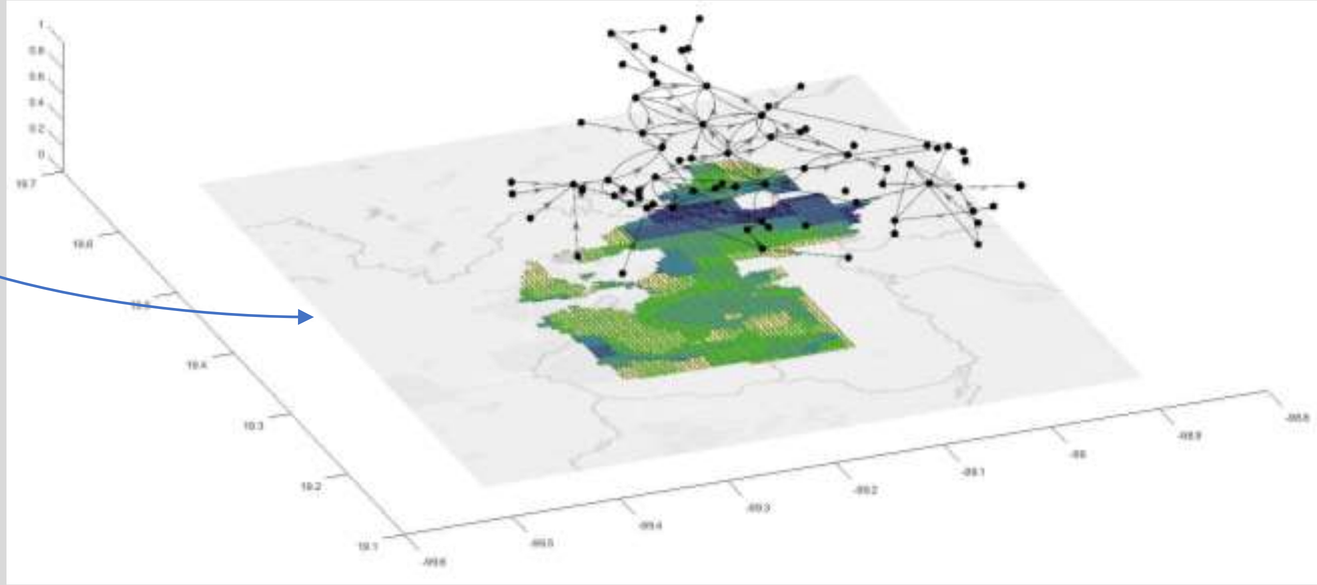


Measuring resilience | resilience **to what**

Climate
Demographics and Demand
Earthquakes
Social Conflict
Maintenance
Public Policy
Finance

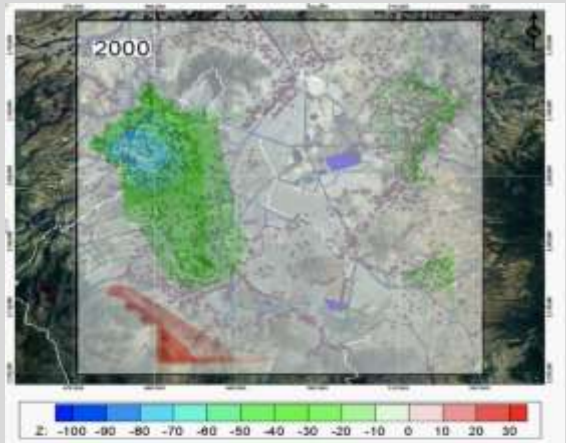
Measuring resilience | what can be done

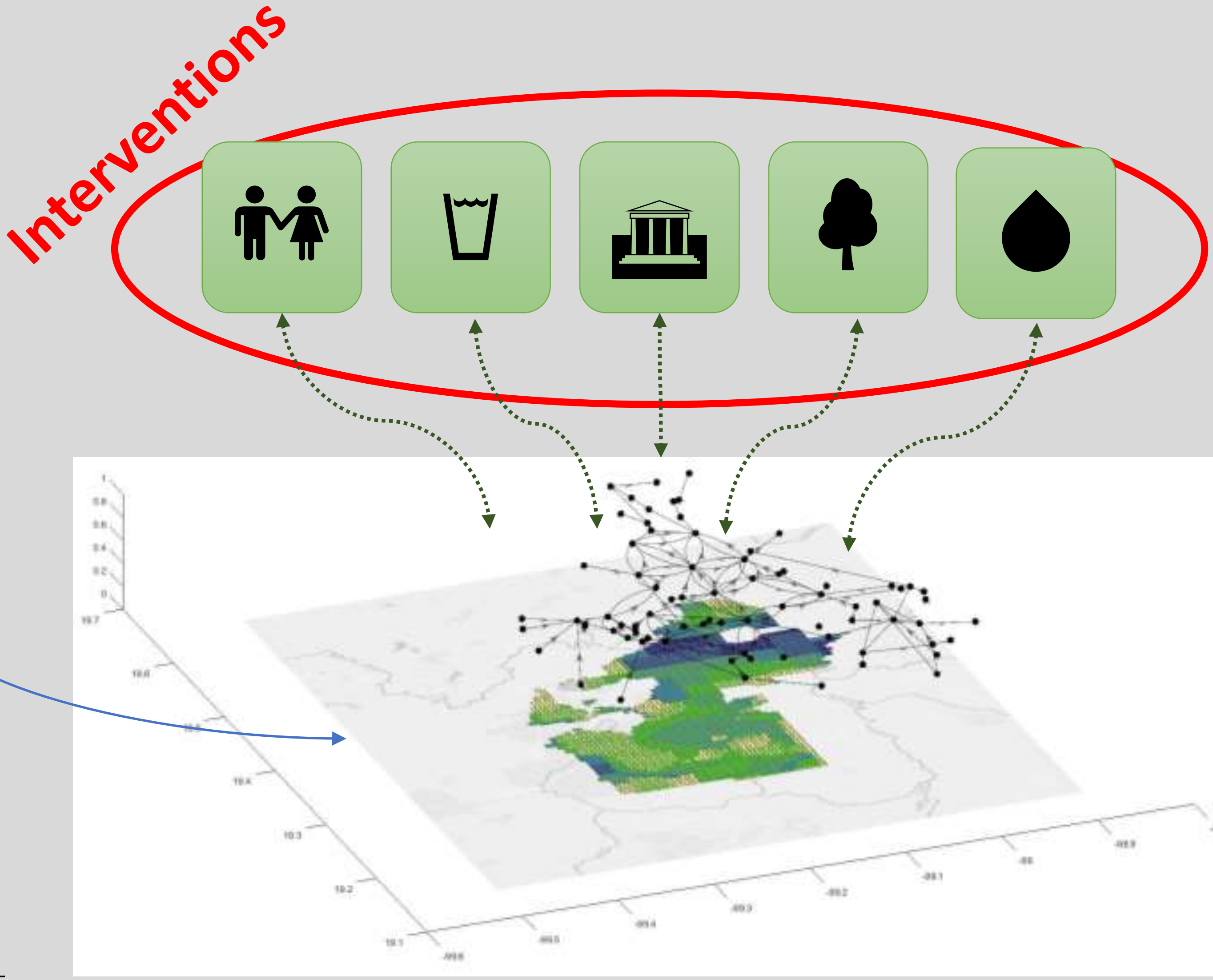




**Fuente: Cruickshank C y Palma A., (2008)*. *The numerical modelling of Mexico City aquifer, Proceedings, ISSMGE TC36 Workshop: Geotechnical Engineering in Urban Areas Affected by Land Subsidence, Mexico D.F*

Measuring resilience | what can be done





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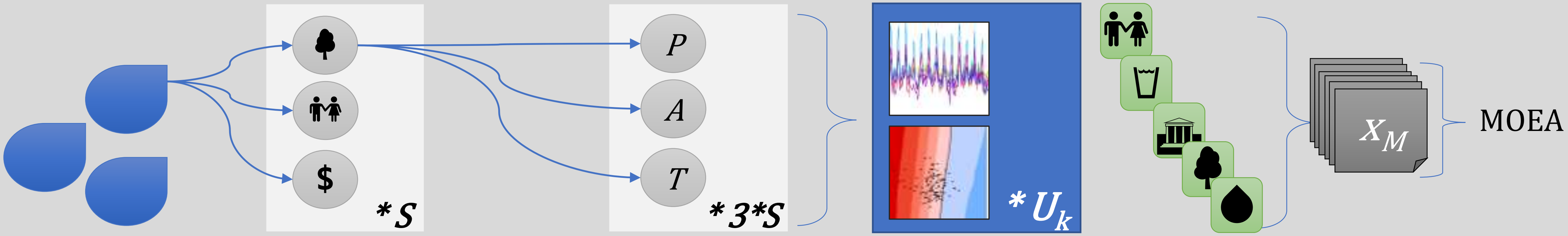


1. Definition of S critical subsystems.
2. Definition of performance targets for environmental (E), social (S) and economic (C) objectives for each subsystem.
3. Selection of locally salient resilience metrics to represent persistence (P), adaptation (A), and transformation (T) of system performance.
4. Definition and exploration of uncertainty scenarios (U_k) for all subsystems. A preliminary sensitivity analysis should be taken to reduce the dimensions of uncertainty to those which are most important to the system. Each resilience metric will be evaluated as a function of these uncertainties (i.e. the problem becomes an optimization for robustness of each resilience metric). This approach represents an important departure from current approaches of measuring resilience.
5. Definition of decision variables, x_M, which at present is a generic variable to represent all investments, policies, and other operational decisions within the systems at all stages.

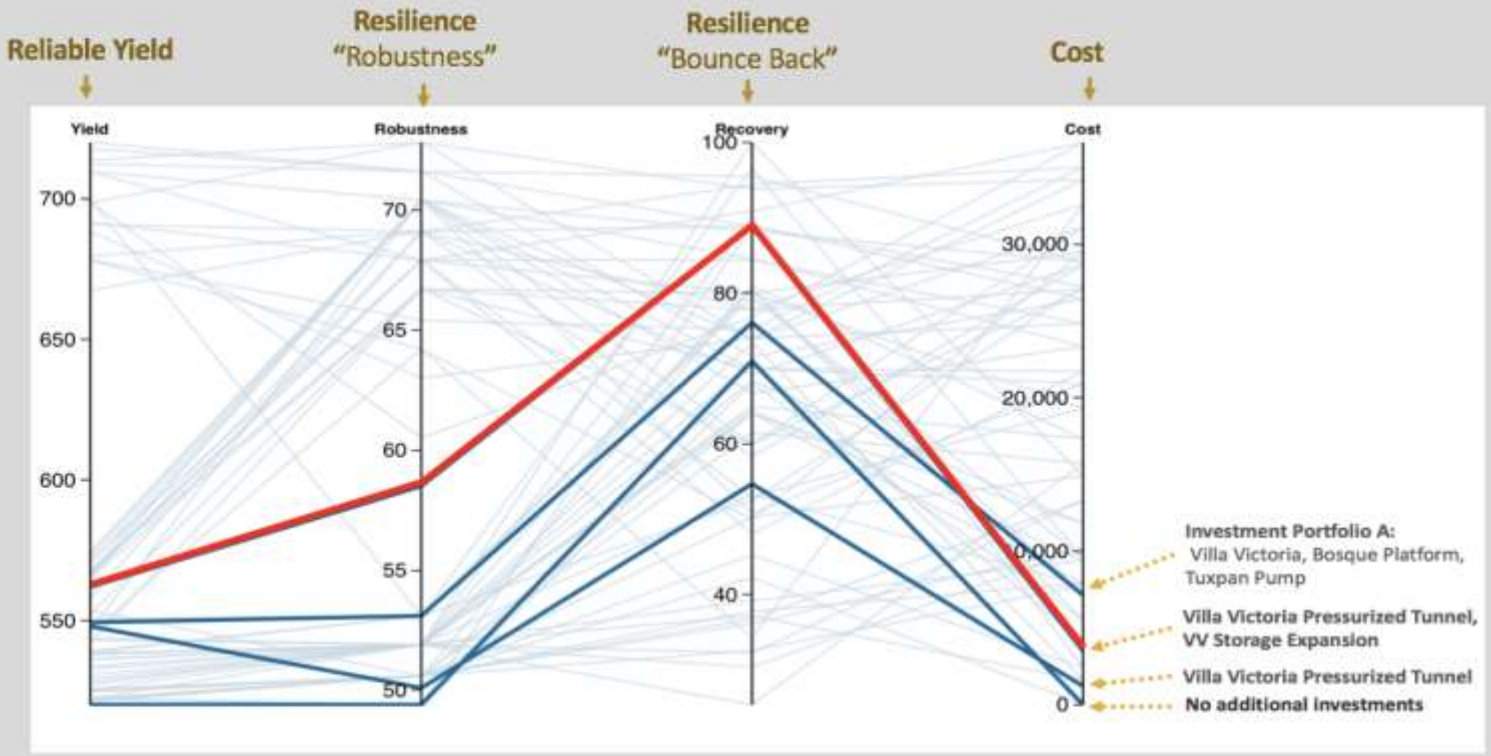
RESILIENCE

of what → to what → and what can be done

What are we finding so far?

Early Results

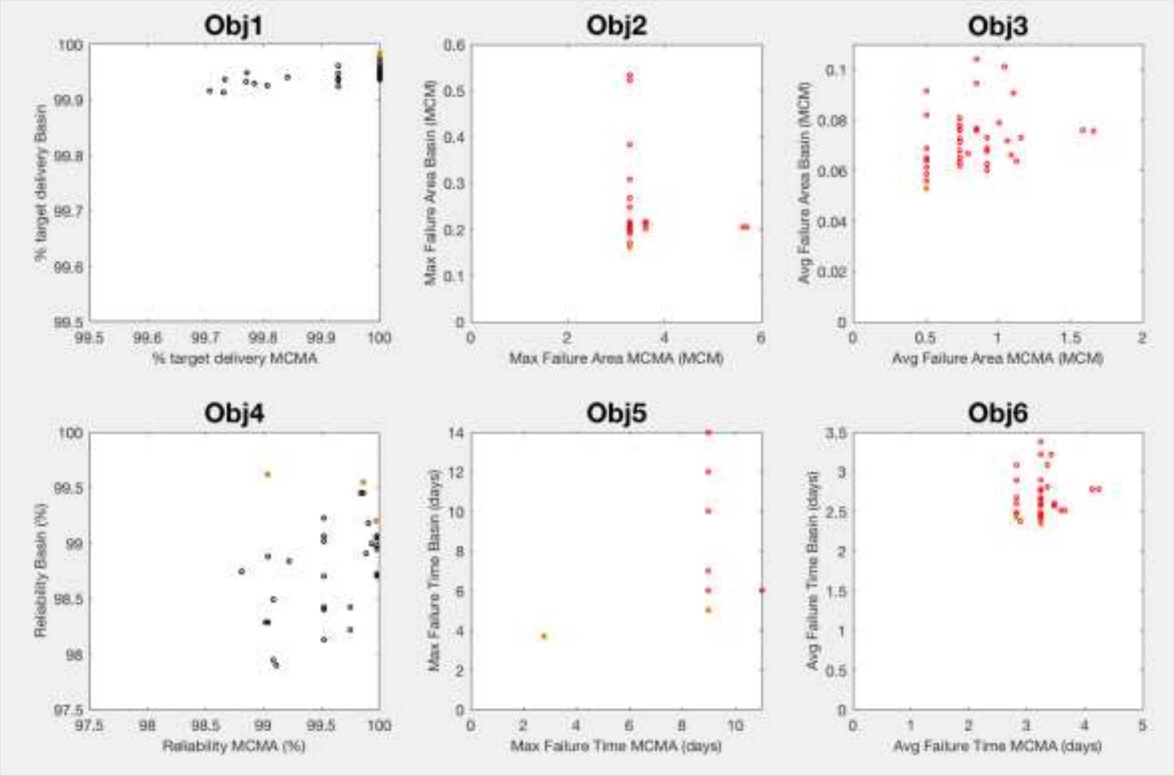
- Evaluating investments/actions based on resilience helps to identify solutions that will be robust to multiple futures.



Early Results

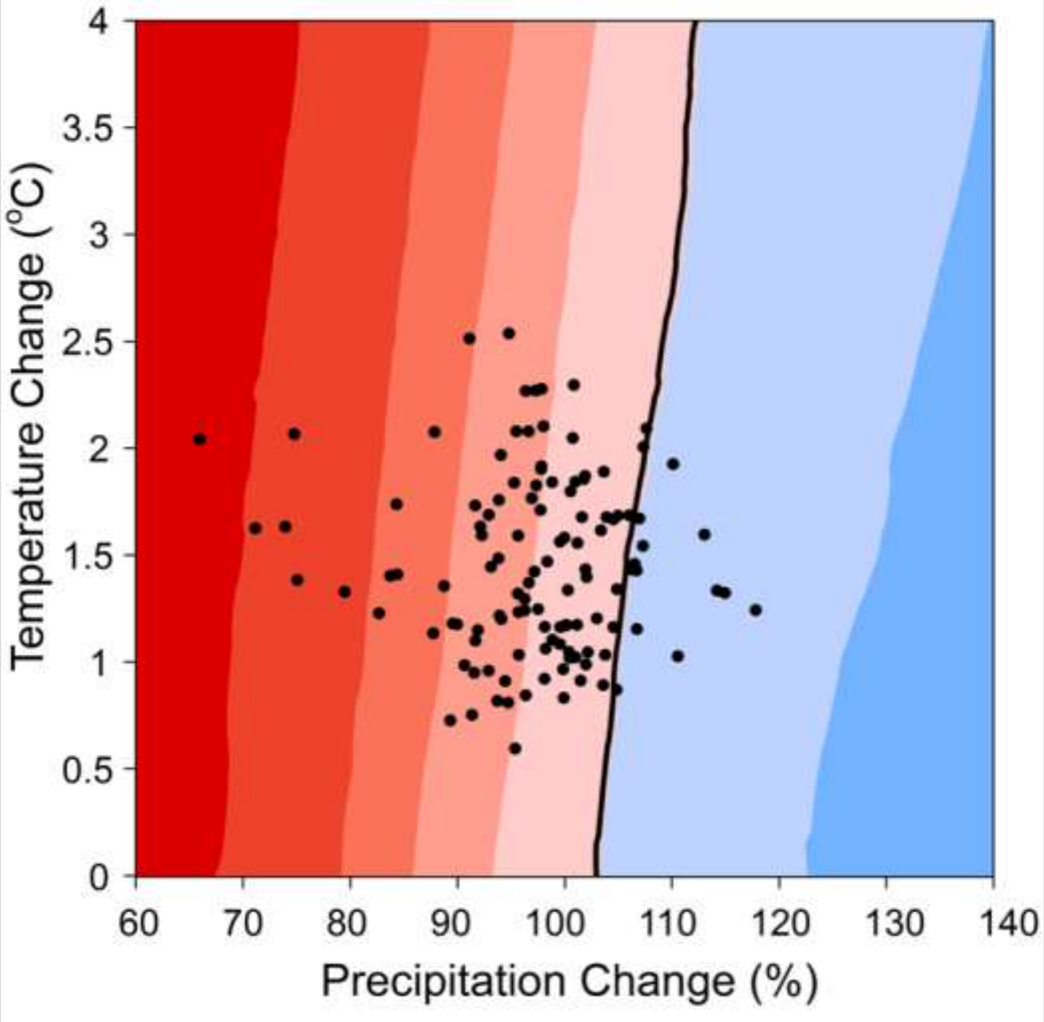
- Evaluating investments/actions based on resilience helps to identify solutions that will be robust to multiple futures.

- How we measure resilience matters



Early Results

- Evaluating investments/actions based on resilience helps to identify solutions that will be robust to multiple futures.
- How we measure resilience matters
- Systems approaches necessary

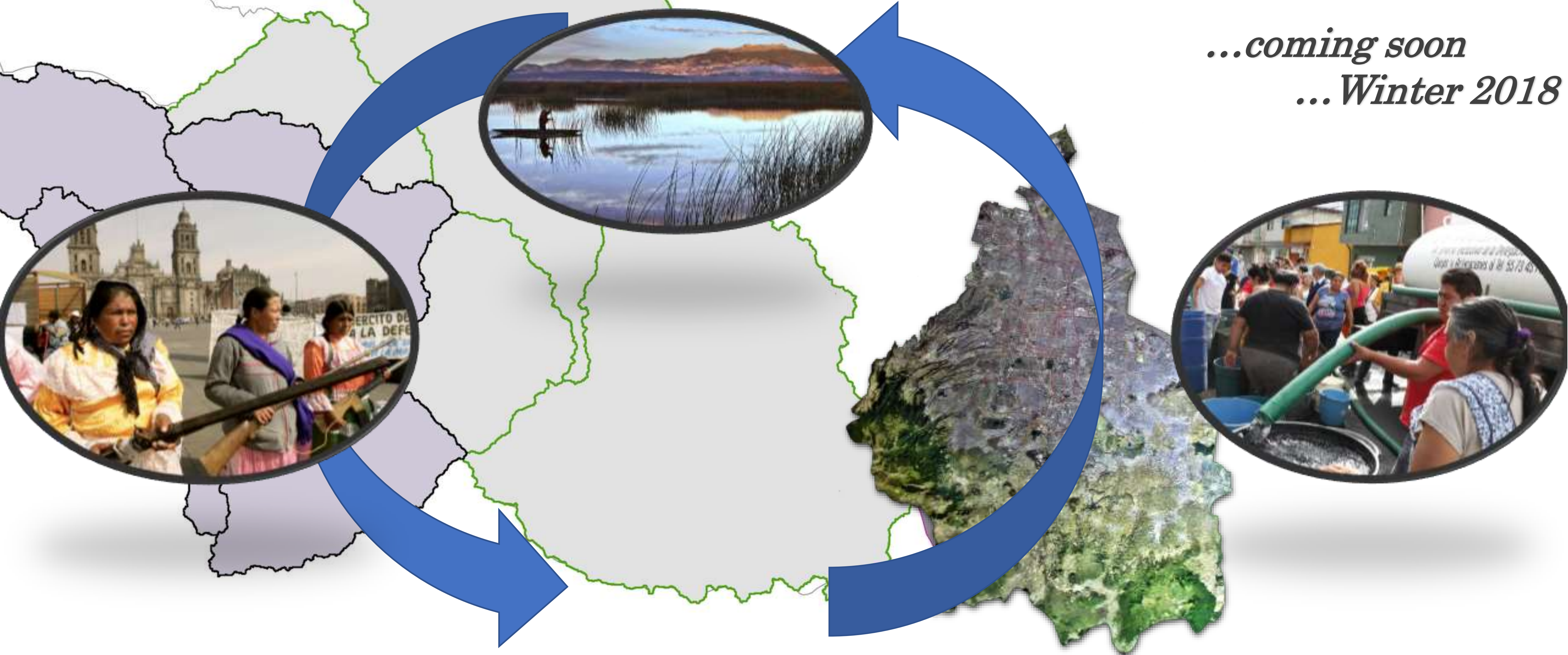


~~Mexico City's Water~~

The Valley of Mexico's Water

...coming soon

...Winter 2018



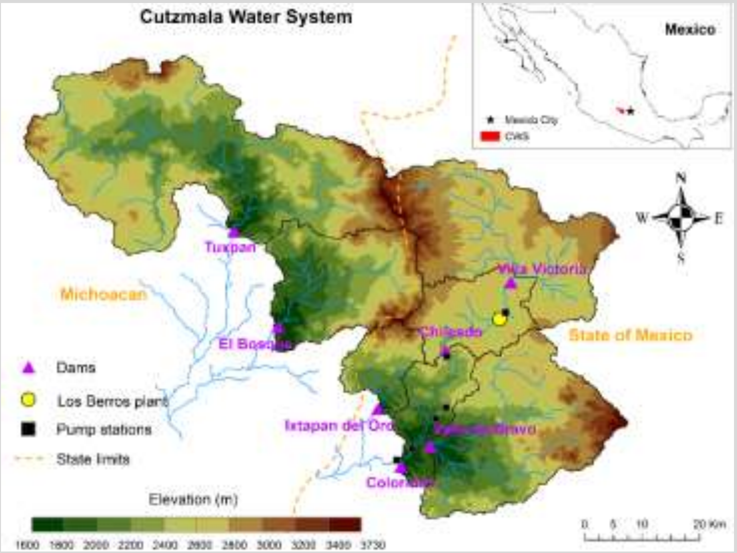
Gracias

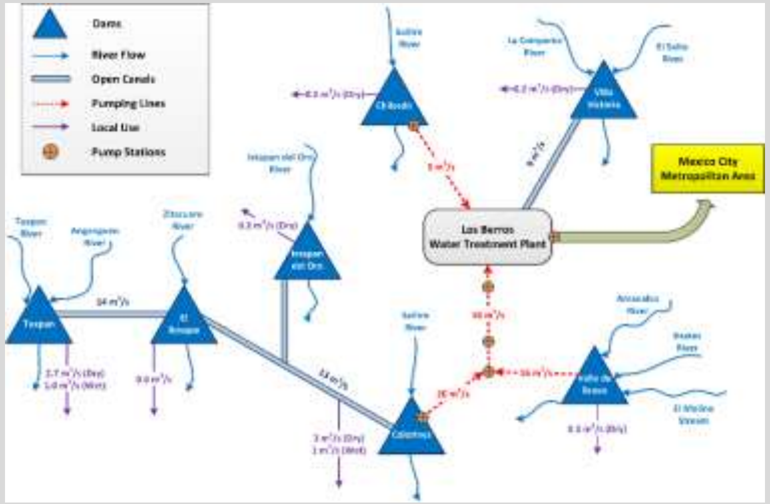
sefreeman@umass.edu

Additional Observations

$$
\begin{aligned}
&Maximize\colon \left(R_{i,j,E,}(x_M, U_k), R_{i,j,S}(x_M, U_k), R_{i,j,C}(x_M, U_k)\right)\\
&Minimize\colon (Cost(x_M))\\
&s.t. \quad i \in \{1,2, \dots, S\}\\
&\qquad j \in \{P, A, T\}
\end{aligned}
$$

Cutzamala





Inputs

°C Temperature*

Precipitation*

Objectives

(metrics based on performance targets)

Max MCMA Target Deliveries*

Max Agricultural Target Delivery *

Max equity of allocation

* *Indicates variable treated as uncertain in the analysis*

Internal Variables

Systems Model

- Network (Pipes & Canals)
- Pipe and Canal Capacity
- Reservoir capacities *
- Reservoir and pumping station operations
- Agricultural withdrawals*

Decision Variables

- Investment options
- Reservoir operations

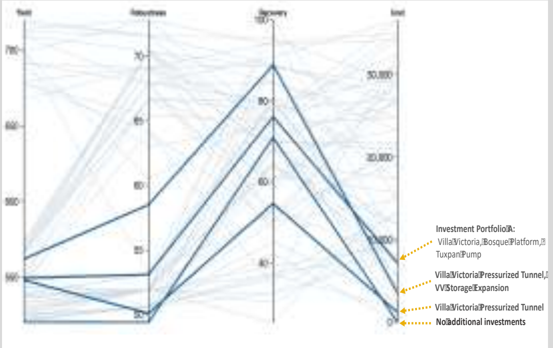
Outputs

Simulated vs Target Deliveries

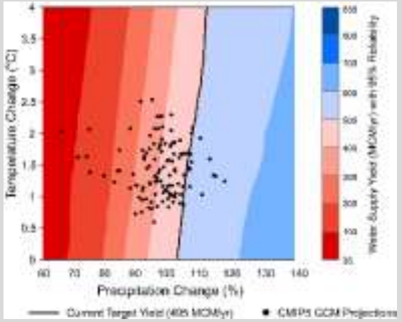
Performance Metrics

Investment Portfolios

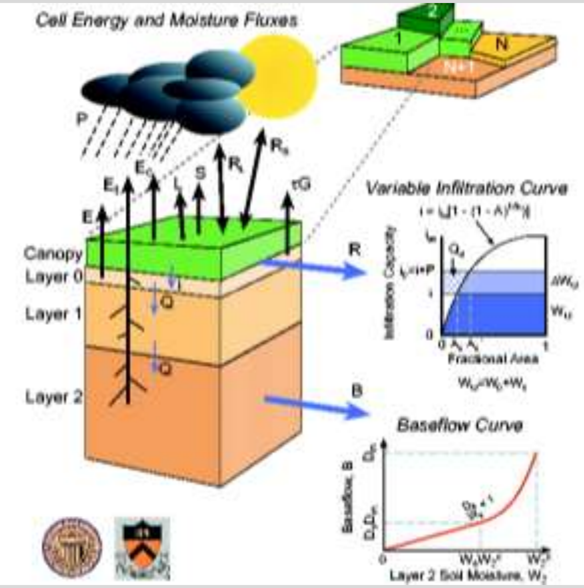
All combinations of decision variables

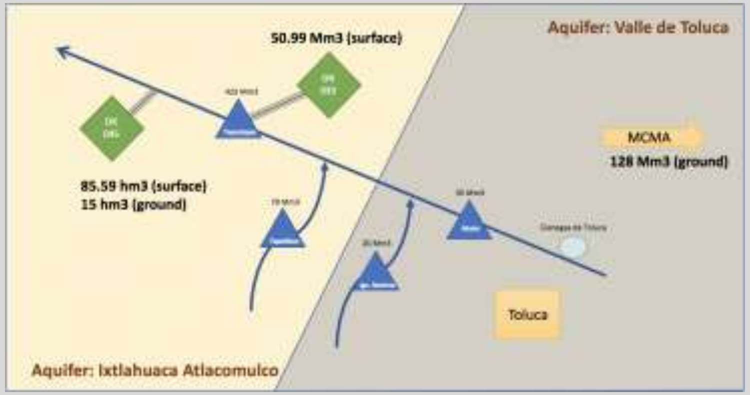


Across uncertainties (states of world)



Lerma





Hidrologia + Sistema

Inputs

Temperature (max/min)*

Precipitation*

Objectives

(metrics based on performance targets)

Max MCMA Target Deliveries*

Max Municipal & Industrial Target Deliveries*

Max Agricultural Target Delivery *

Max Environmental Target Delivery (Cienegas de Toluca) *

Max equity of allocation

** Indicates variable treated as uncertain in the analysis*

Internal Variables

Systems Model

- Network (Pipes & Canals)
- Reservoir capacities
- Reservoir operations
- Agricultural withdrawals*
- Municipal/industrial withdrawal and returnflow*
- Aquifer physical characteristics*

Decision Variables

- Investment options (and associated costs)
- Reservoir operations
- Water allocation

Outputs

Simulated vs Target Deliveries

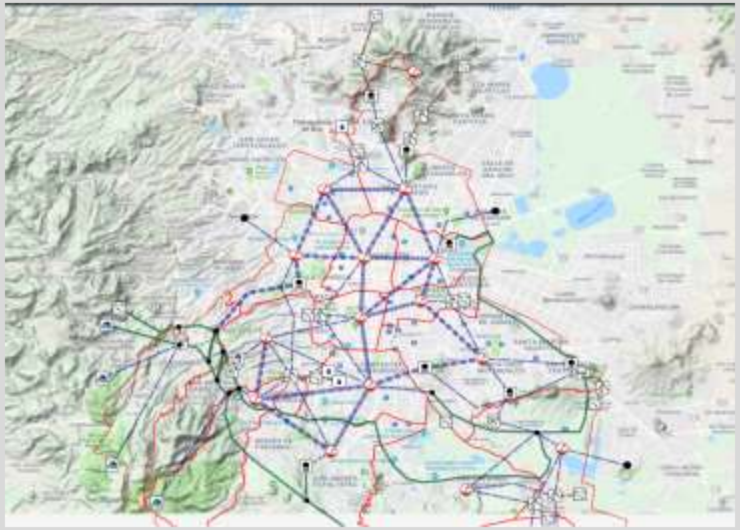
Performance Metrics

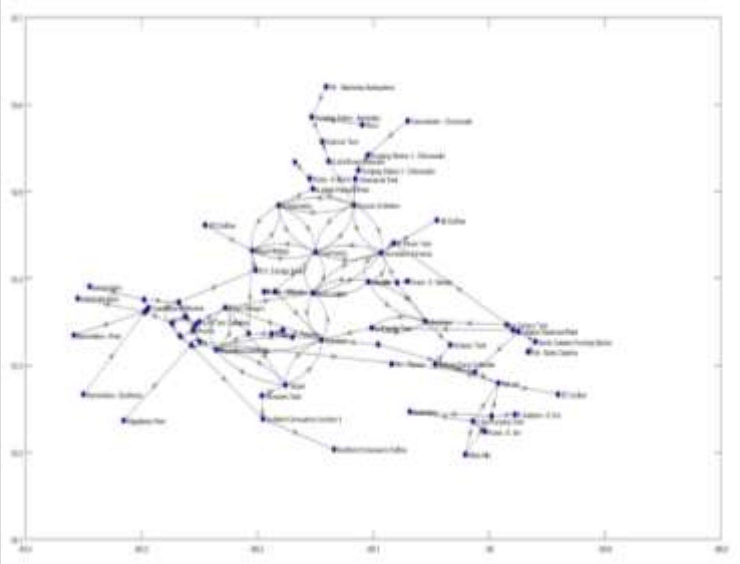
Investment Portfolios

Additional Uncertainties

- Clima
- Demanda y demografia
- Sismos
- Landuse change
- Wastewater reuse

CdMX





Inputs

- Cutzamala*
- Lerma*
- Manantiales & Magdalena*
- Groundwater model outputs*
  (which requires temperature and precipitation inputs which are converted to recharge)

Objectives

(metrics based on performance targets)

- Max delivery at each delegation (based on target for domestic, industrial and agricultural uses)*
- Min aquifer storage depletion and subsidence*
- Max equity of allocation*

*** Indicates variable treated as uncertain in the analysis***

Internal Variables

Systems Model

- *Network (system connectivity)*
- *Storage tanks (≥50,000 m^3)*
- *Pumping stations (≥ 0.5 m^3/s)*
- *Demand nodes at each delegacion*

Decision Variables

- Investments/actions
- Water sources (i.e. how much water taken from each source)
- Storage tank operations (i.e. release coefficients)
- Operations (i.e. how water distributed from each source to each demand node)

Outputs

- Simulated vs Target Deliveries to delegaciones
- Performance Metrics
- Investment Portfolios
- Subsidence

Additional Uncertainties

- Climate
- Demand and demography
- Earthquakes
- Leakages
- Finance