

# Creating Policies Around How Cities Outsource Water: Disaggregating Virtual Water Trade to the Watershed Level to Increase Municipal Resilience

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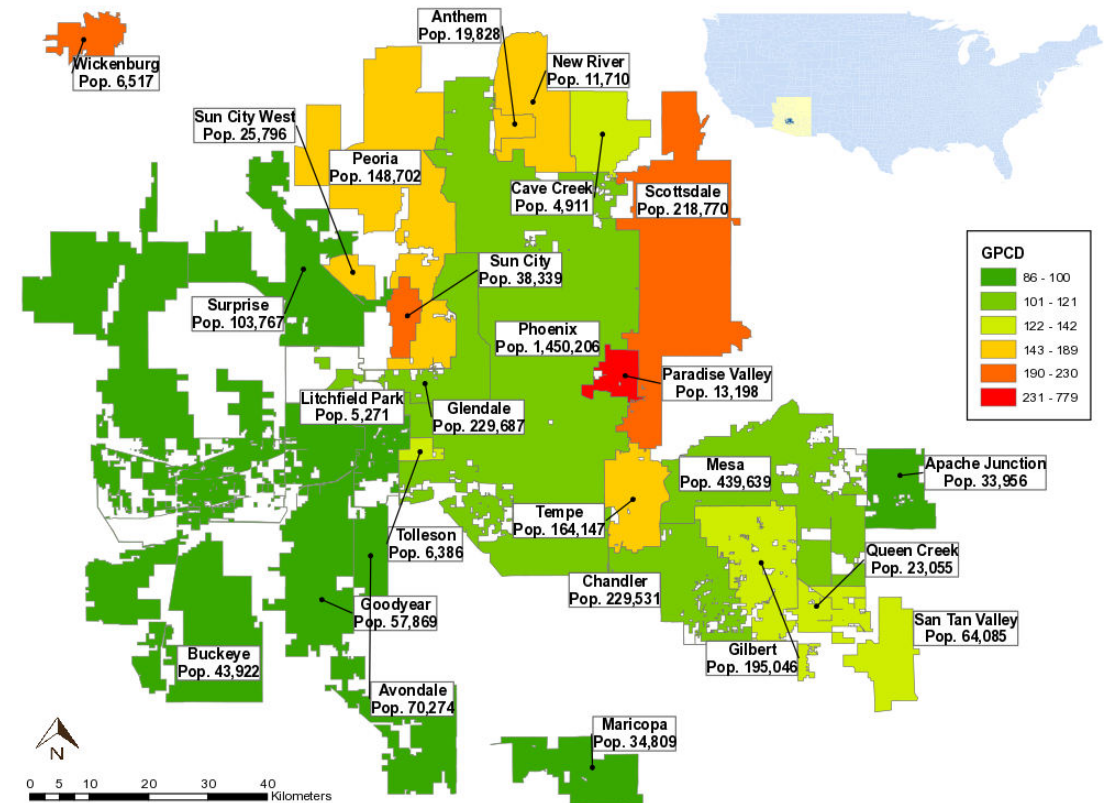
Edinburgh, UK

# Introduction

- Virtual Water Flows and Net Water Footprint at three scales
  - National for the Metropolitan Area and Individual Cities
  - Metropolitan Area for Each City
  - Within City Flows
- Guiding Questions:
  - How water is indirectly shared through economic activity between cities within the metropolitan area and the metropolitan area and the US?
  - Is there a typology of cities based upon water outsourcing characteristics?
  - Can downscaled virtual water trade networks provide information on urban resilience?

# Study Area – Phoenix Metropolitan Area

- 25 municipalities surrounding the city of Phoenix, which have a combined population of 3.69 million people.
- Urban “core” cities in the PMA are Phoenix, Mesa, Scottsdale and Tempe
- Agricultural lands that surround the PMA face development pressures from expanding suburban municipalities.
- Major physical water resources for the PMA are the Colorado River via the Central Arizona Project (CAP); the Salt and Verde rivers, via the Salt River Project (SRP); and substantial, but nonrenewable groundwater underlying the PMA.



# Data

- US Commodity Flows – Freight Analysis Framework (FAF3) from Oak Ridge National Labs
- USGS Water Use of the Nation
- Self-report consumption data by PMA utilities and water providers
- Maricopa County Trip Reduction Program
- US Census, Economic Census
- USDA National Agricultural Statistics Survey

# Methods

Data were used to calculate three virtual water flows and a water footprint balance for each Phoenix metropolitan area municipality.

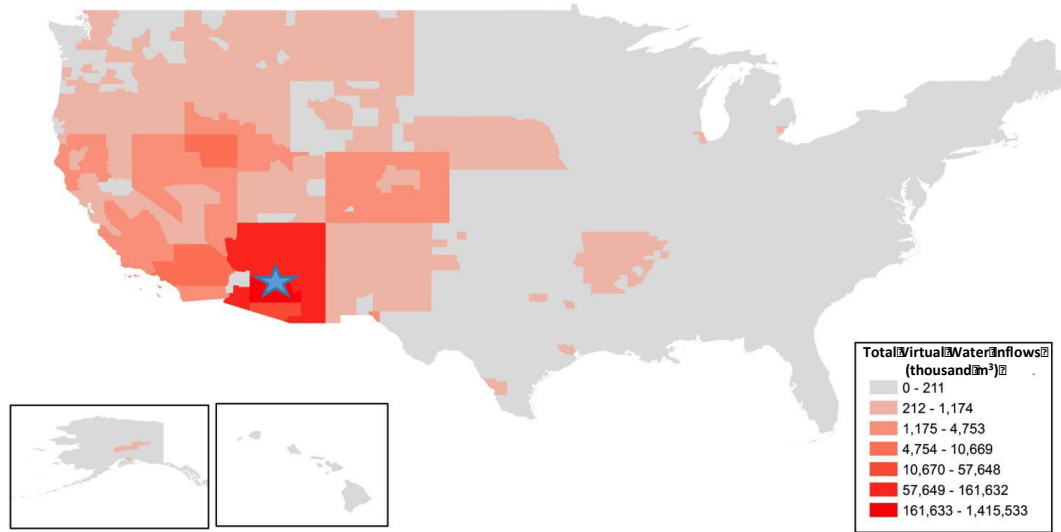
1. Virtual Water Flows from the Metropolitan Area to the Nation
  - A commodity flow based virtual water model for the United States based on regional shares of population, agriculture, and employment.
2. Intra-Metropolitan Area Virtual Water Flows
  - A network-based commuting flow model using the distance between cities as a deterrence to commuting
3. Calculating a Complete Water Footprint Balance for the Phoenix Metropolitan Area and Component Municipalities
  - Water footprint balance ( $E_m$ ) calculated for each municipality using direct ( $U$ ) and virtual water flows ( $V$ ) with the Embedded Resources Accounting Framework
  - $$E_m = U_{urban} + U_{farm} + V_{C,In} + V_{L,In} - V_{C,Out} - V_{L,Out}$$

# Virtual Water Flows

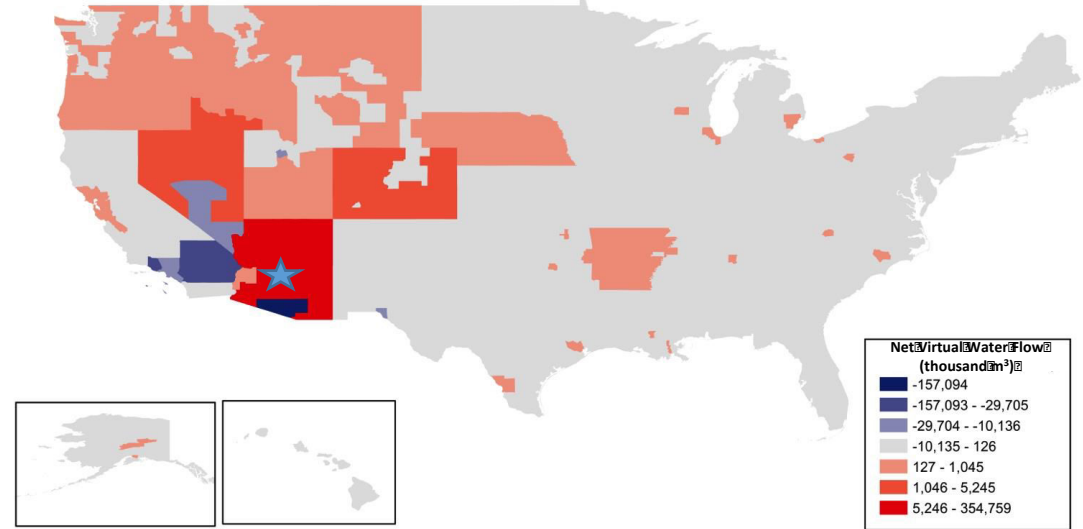
Economic Sector	Type of Water Flow	Type of Trade	Description of Flow	ERA Variable
Goods Producing	City-Level Direct Withdrawal	Commodity	Direct water consumption for agricultural production.	
Goods/Services	City-Level Direct Withdrawal	Commodity/Labor	Direct consumption of potable deliveries for industrial, commercial production and residential use.	
Goods Producing	Intra-MA Virtual Water	Commodity	Water withdrawn to produce commodities (agricultural, commercial, industrial) that are consumed in another municipality within the MA.	
Multiple (Industrial, Commercial, Service)	Intra-MA Virtual Water	Labor	Residential potable deliveries in one municipality for a workforce employed in another municipality.	
Goods Producing	Country	Commodity	Water used to produce agriculture, industrial, and commercial commodities for consumption in a different geography.	

# Commodity-Flow Based Net Water Footprint

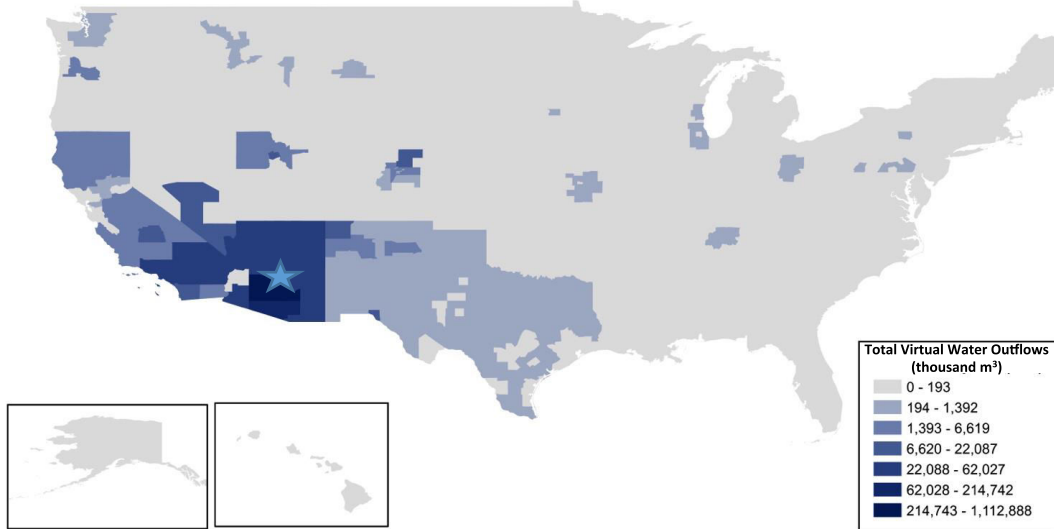
Inflows



Net Flows

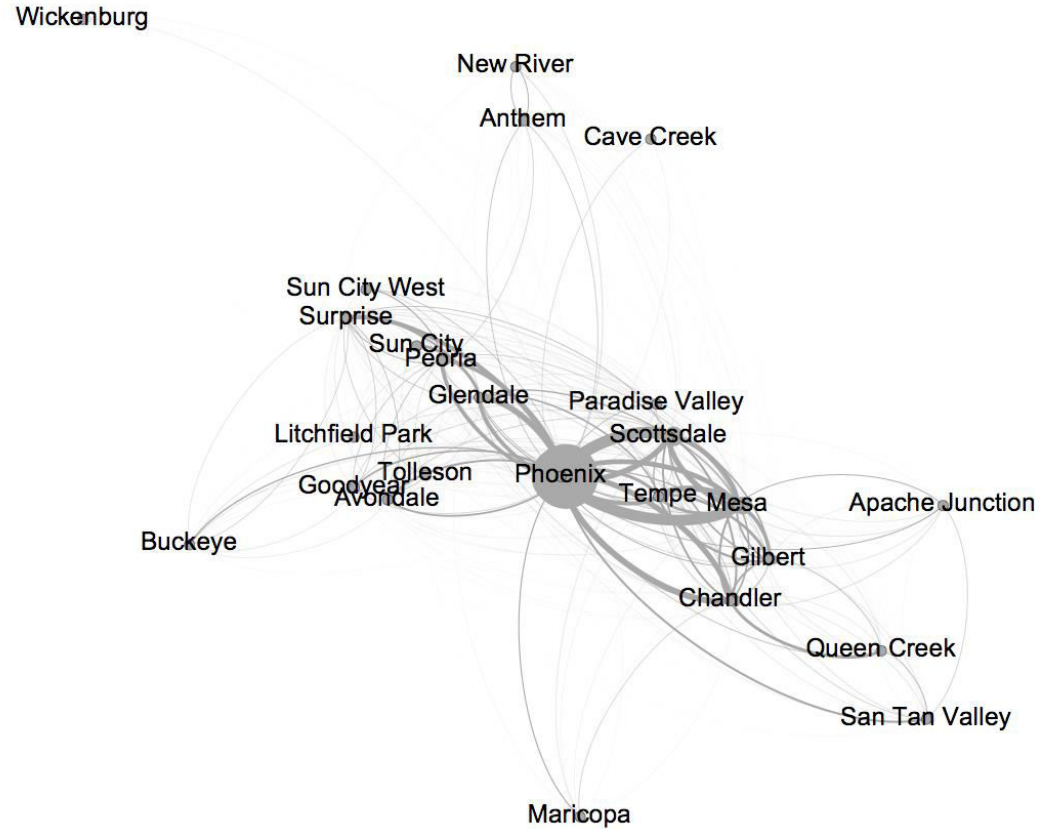


Outflows

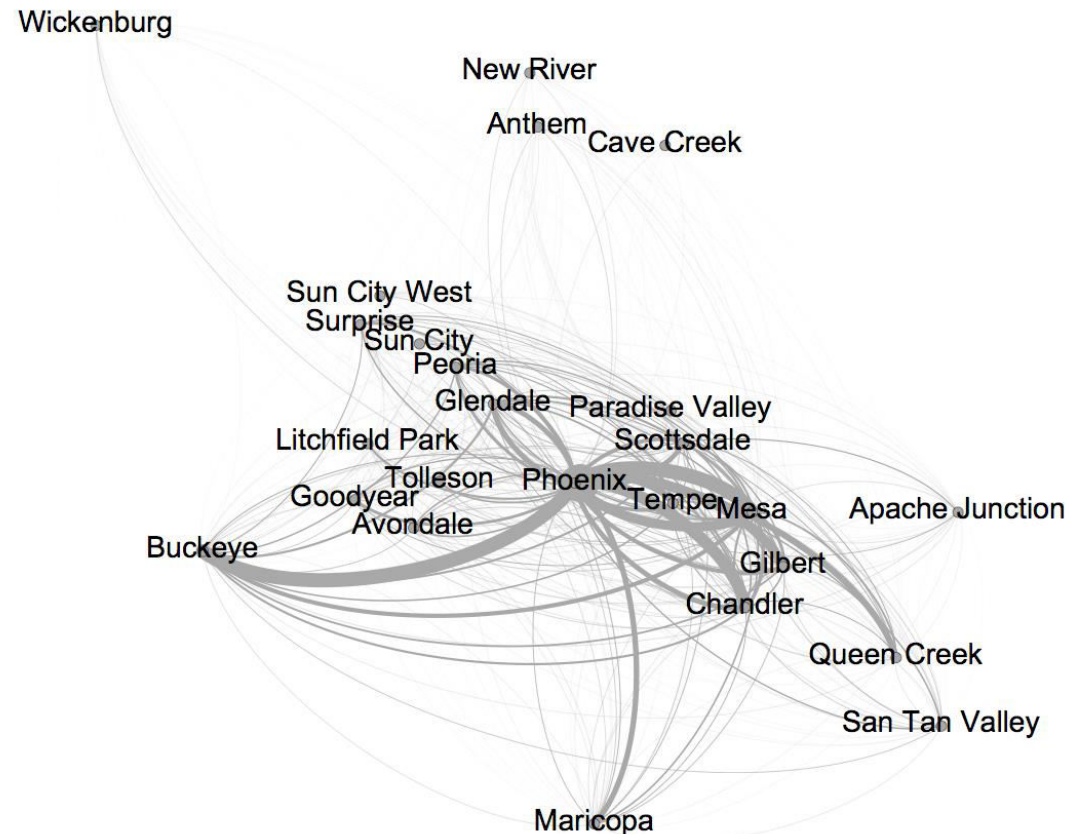


- Virtual water inflows (4,125 Mm<sup>3</sup>) are skewed to the dry western United States. Agriculture dominates virtual water inflow, especially from Nebraska, Arkansas, and California
- Virtual water outflows (2,584 Mm<sup>3</sup>) are strongly correlated with the transportation route of the Interstate 10 highway and associated railways, which connects the PMA to markets in California, New Mexico and Texas.
- Net virtual water inflows for the PMA ( $E_{PMA}$ ) are shown above. While virtual water inflows are greater than outflows, when disaggregated to the county-level it is evident that the PMA is both a net importer and exporter depending on trading partner.

# Virtual Water Flows within the PMA



(Left) Graph representation of estimated labor flows, represented with network edges, within the Phoenix metropolitan area. Phoenix is the dominant commuter city within the metropolitan area attracted much of the commuter flow from surrounding municipalities and having a substantial flow of within city commuters.

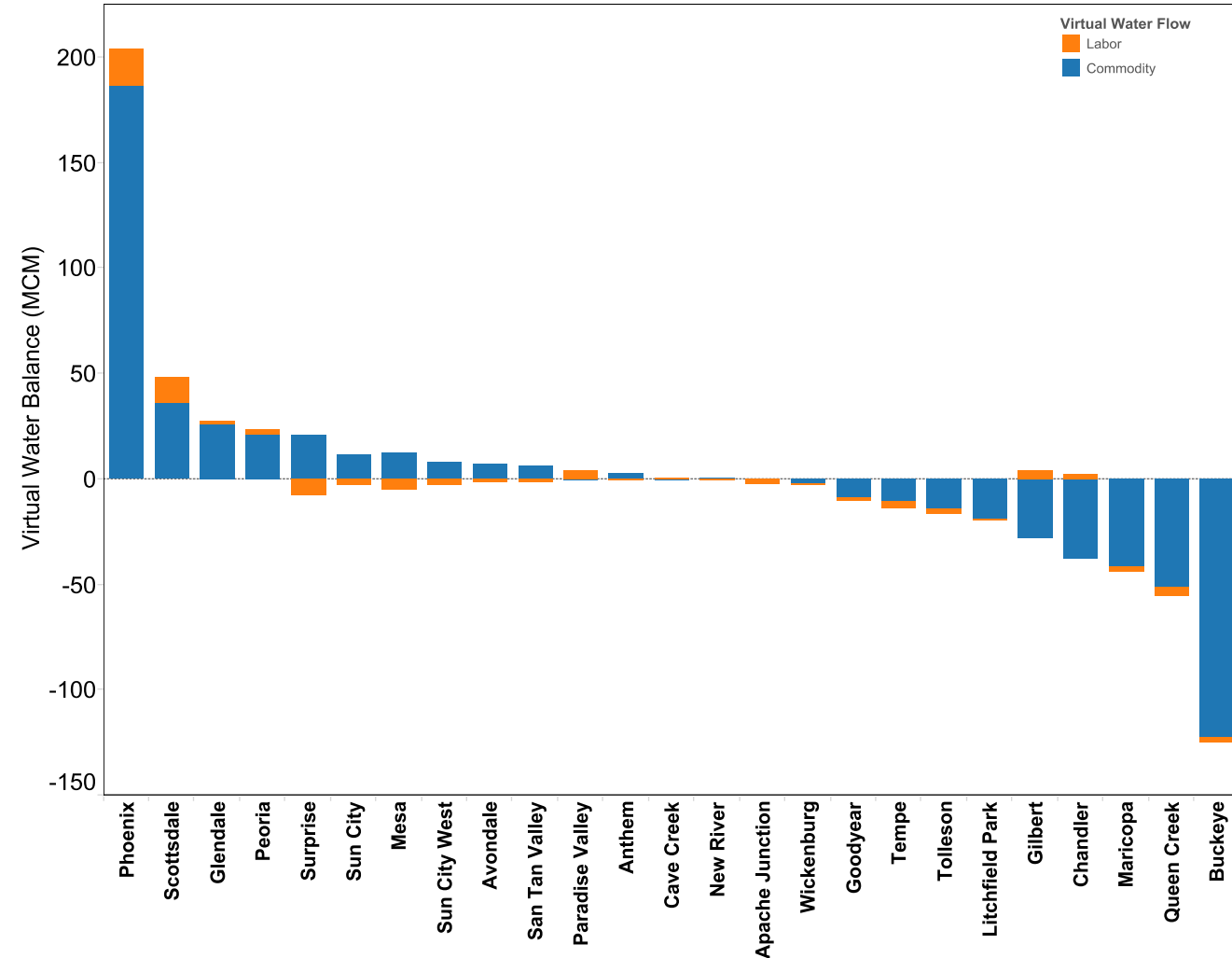


(Right) Estimated commodity flows within the Phoenix metropolitan area, where the size of the flow is proportional to edge weight. Phoenix is still the central city with respect to commodity flows, but large agricultural areas (Buckeye, Gilbert, and Queen Creek) and industrial cities (Mesa, Tempe, and Chandler) also play significant roles within the Phoenix metropolitan area economy.



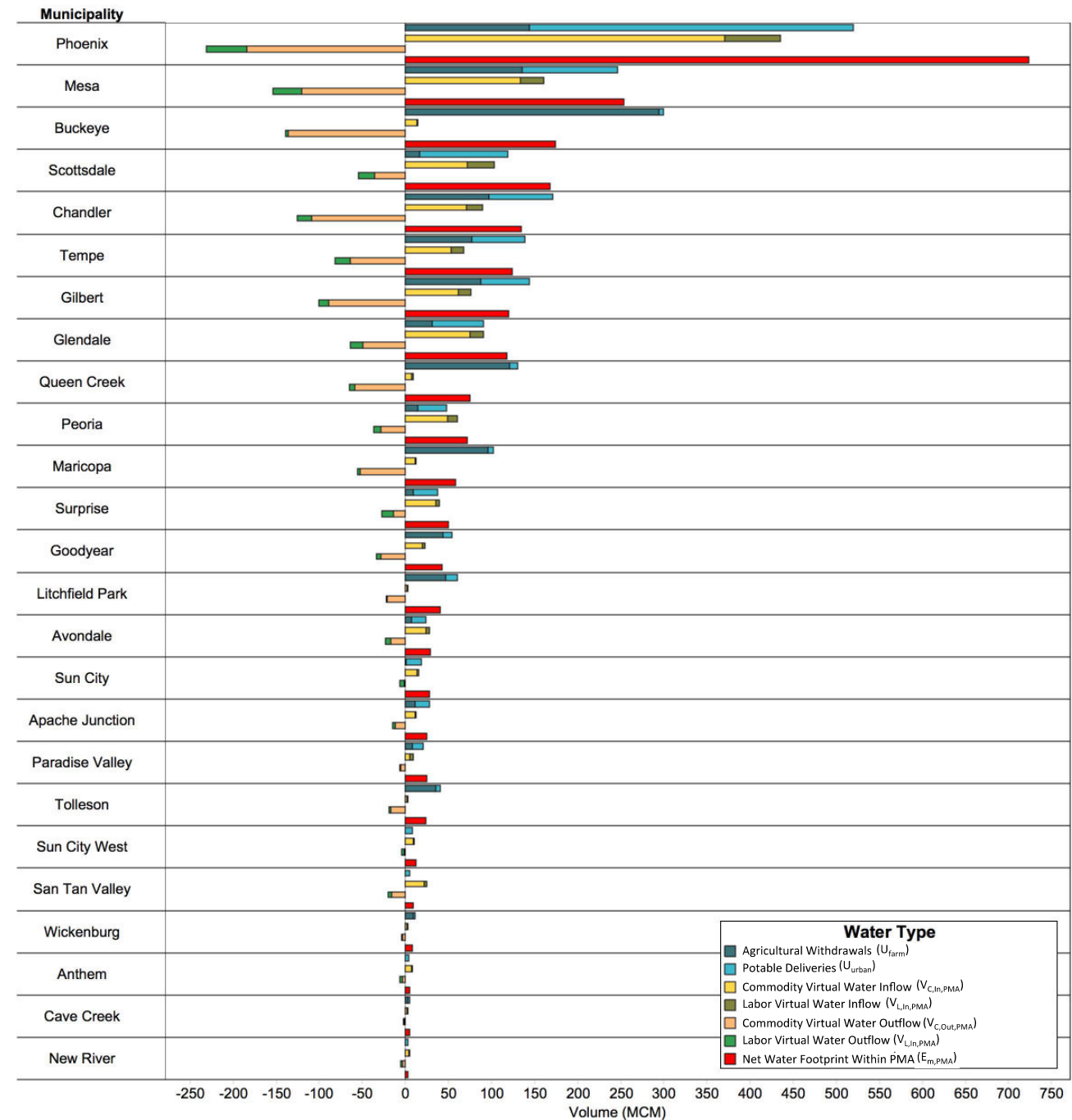
# Virtual Water Flows within the PMA

- The core cities, chiefly Phoenix and Scottsdale, are net virtual water importers with respect to commodities and labor.
- Surrounding cities support the core cities via the virtual water outflows in the form of labor (commuting) and commodities
- A large fraction of the net commodity inflows and outflows is due to the virtual water associated with agricultural commodities, which fall outside of municipal water supply systems.



# Virtual Water Flows within the PMA

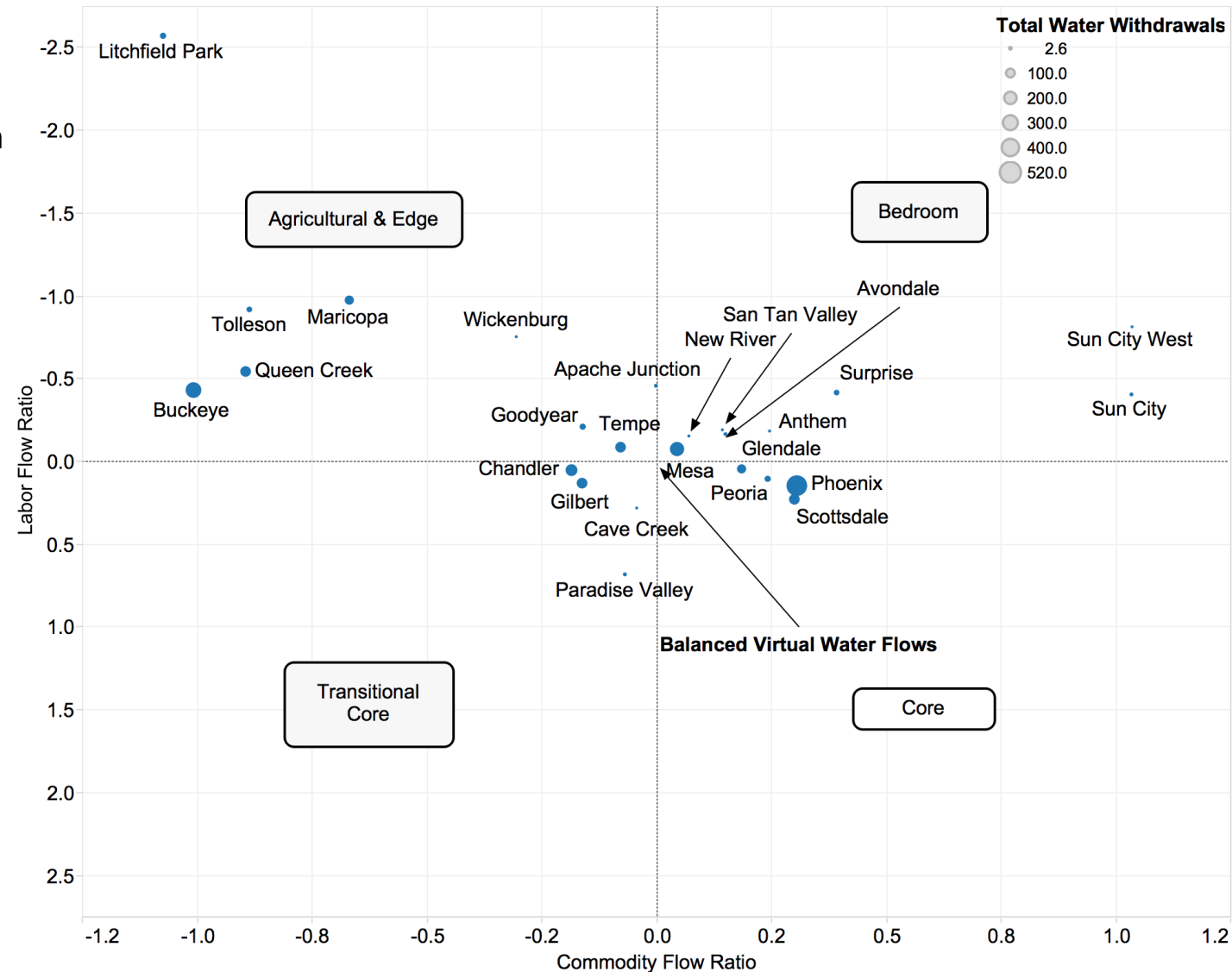
- PMA municipalities share the same physical water resources
- Further, PMA municipalities share physical water resources through metro area economic activity .
- Net water footprint within the PMA boundary represents an adjusted water allocation after taking into account water sharing.



# Virtual Water City Typology in the PMA

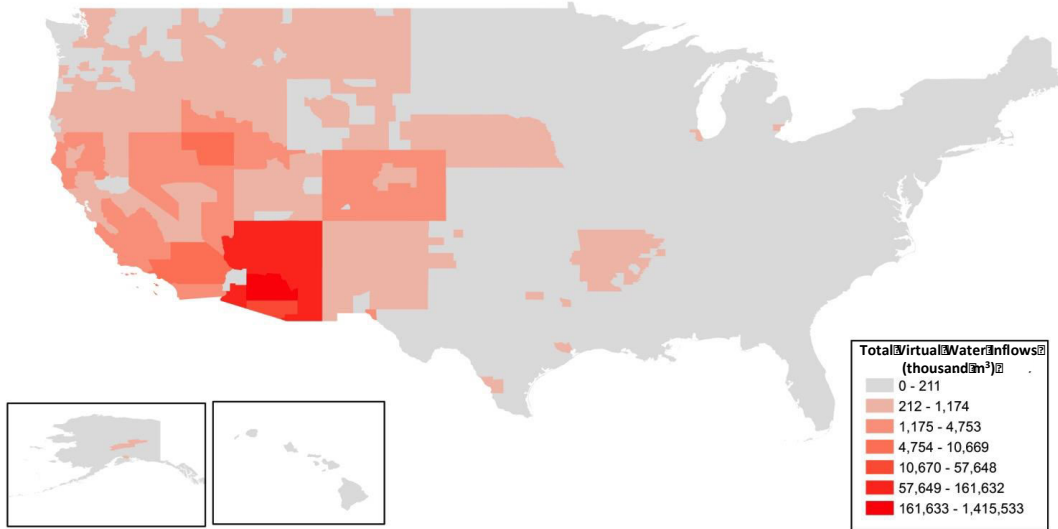
City typologies based on virtual water flow:

- “core” municipalities dependent on their intra-metropolitan suburban and agricultural municipalities for substantial net virtual water inflows embedded in the labor or local agriculture;
- suburban “bedroom” community municipalities or neighborhoods that are substantial net virtual water exporters to core municipalities via labor flows due to the absence of commodity producing economic activities or economic specialization in tertiary and quaternary sectors
- fringe commodity-exporting communities that are substantial net virtual water exporters to metropolitan area municipalities, usually via a local agricultural trade but also via export of energy or manufactured goods consumed primarily within the local metropolitan area;
- small communities and “transitional core” communities, which are economically specialized municipalities that are not substantially interdependent on their neighbors for virtual water inflows embedded in the labor flow.

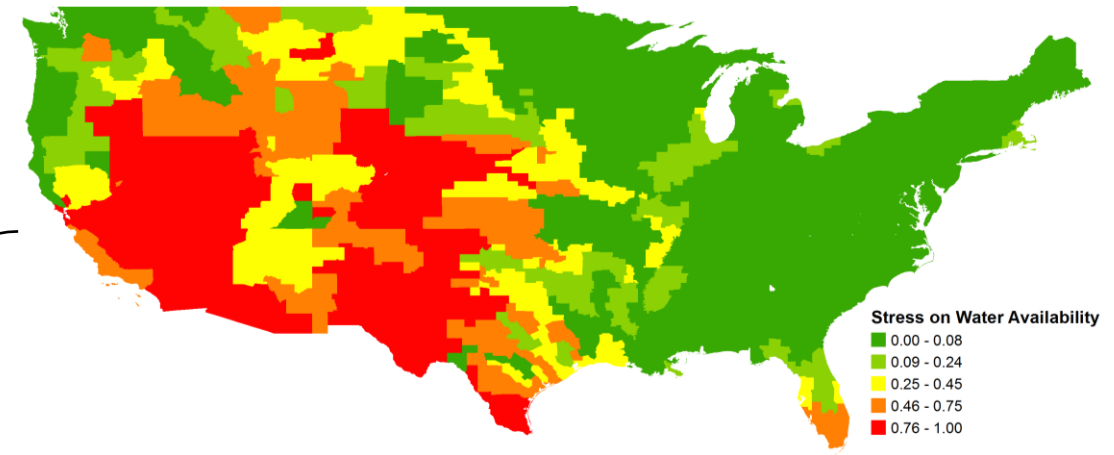


# How stressed are virtual water resources?

Sources of Virtual Water

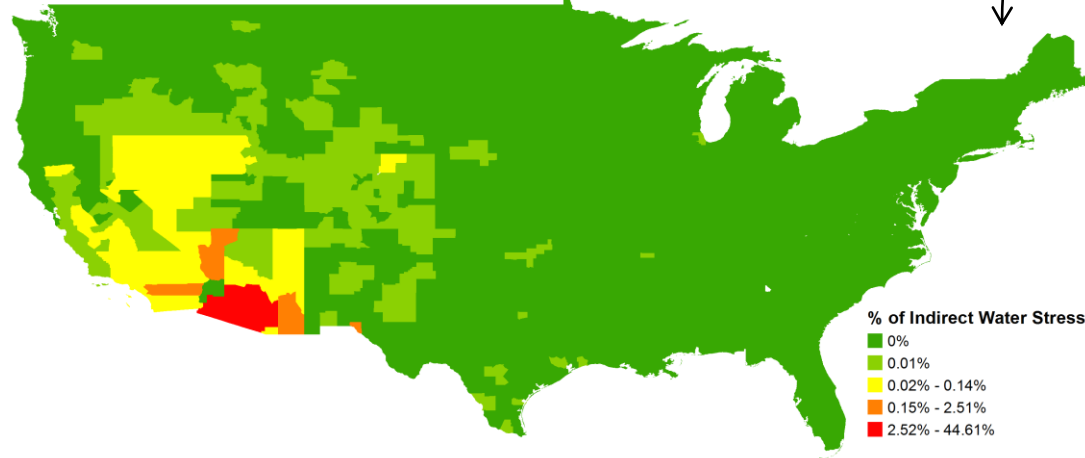


HUC-08 Level Water Availability Index



Source: Tidwell et al. 2011

Virtual water Availability Index



Disaggregating domestic virtual water flows for the PMA provides insight into its exposure to watershed-level stress.

- PMA has a virtual water availability index (0.94) greater than direct water availability index (0.92)
- Identify hotspots in trade network with respect to drought.
- Basis for expanding inter-basin cooperation?

# Conclusions – What about resilience and risk?

- At the metropolitan area scale, virtual water is real water.
  - Potential to provide a buffer against water resource shocks affecting a specific municipality or set of municipalities in the PMA.
  - However, hydro-economic shocks beyond the buffer capacity provided by the local virtual water supply will require major paradigm shifts in how water is managed and consumed.
  - Identifying hotspots for risk within virtual water resources portfolio could reduce risk to non-local water stress.

## Future Work:

- Expanding upon water scarcity footprints
- Incorporating green water into virtual water trade model
- Quantify the potential of cascading failure in trade network with respect to water stress