Virtual Water Accounting Case Study Applications

Case Studies in the Southwest U.S. and Kalamazoo, Michigan

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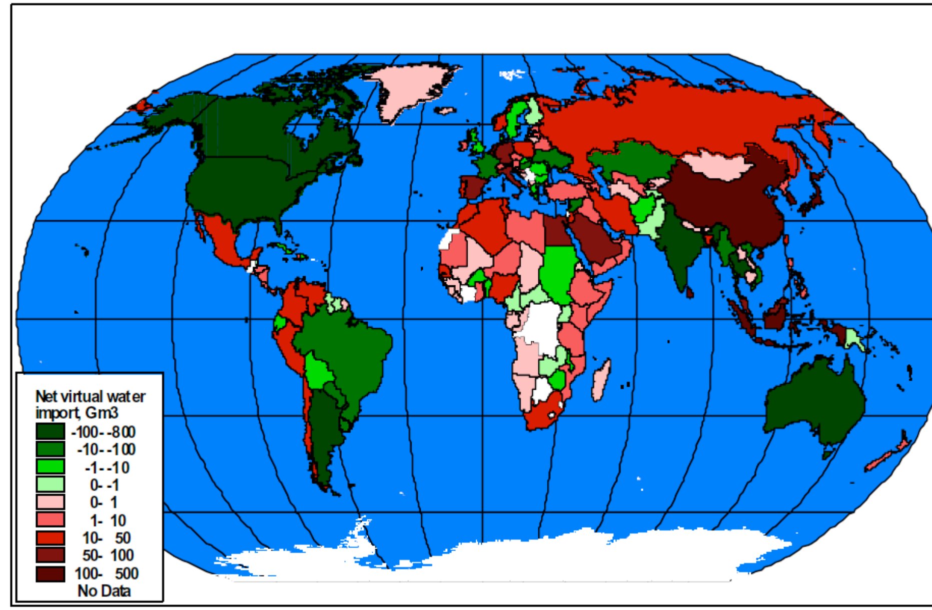
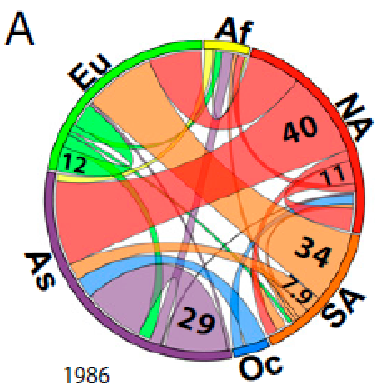
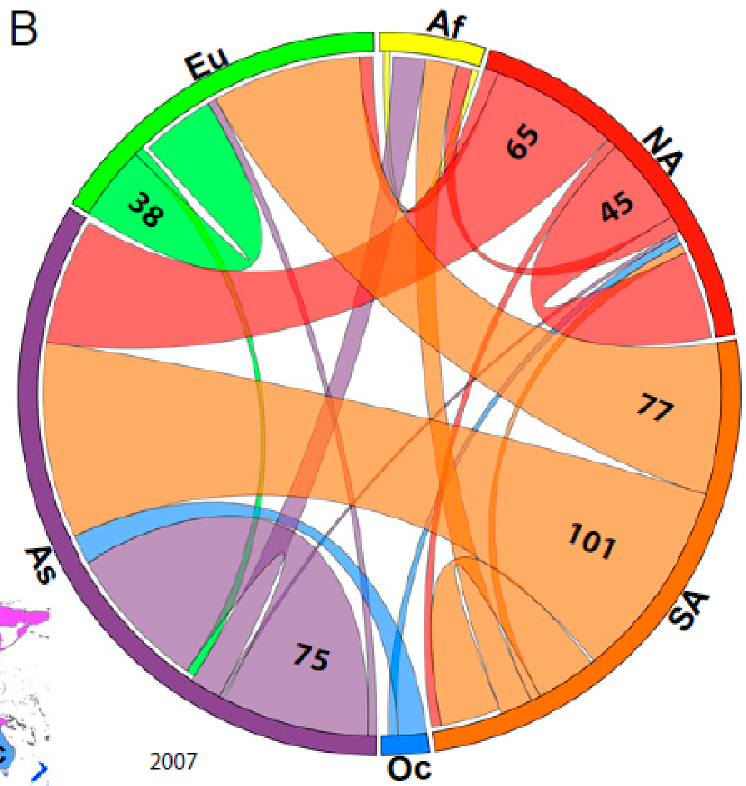
(growth in)
Global Virtual Water Trade

A map of the internationally
outsourced Services of Water,
in exchange for $ in trade.

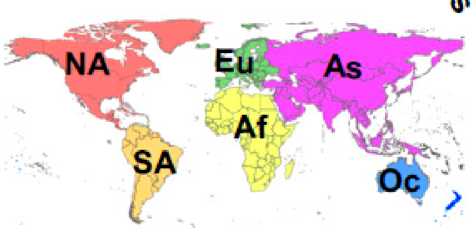


Hoekstra and Chapagain (2007)



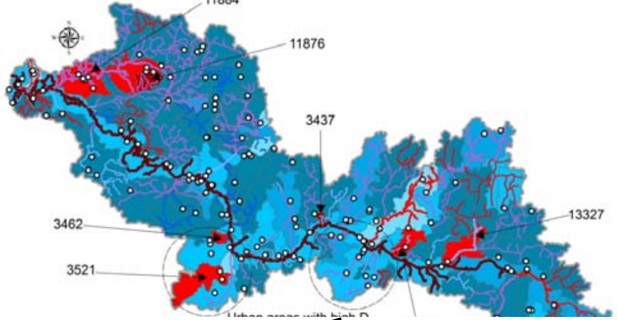


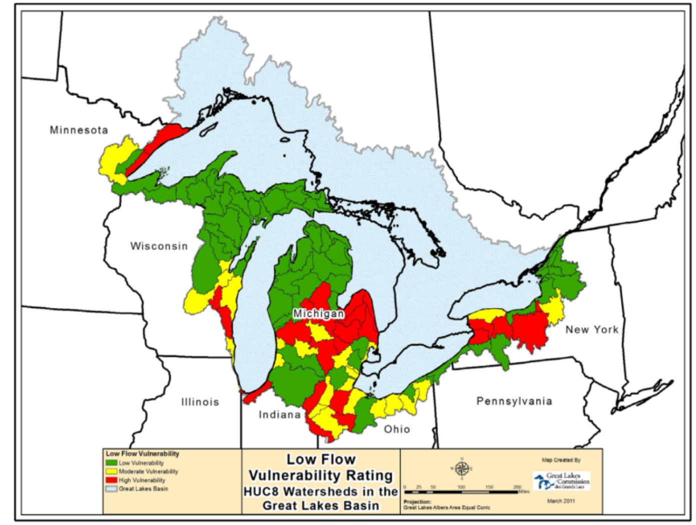
Dalin et al. (2012)



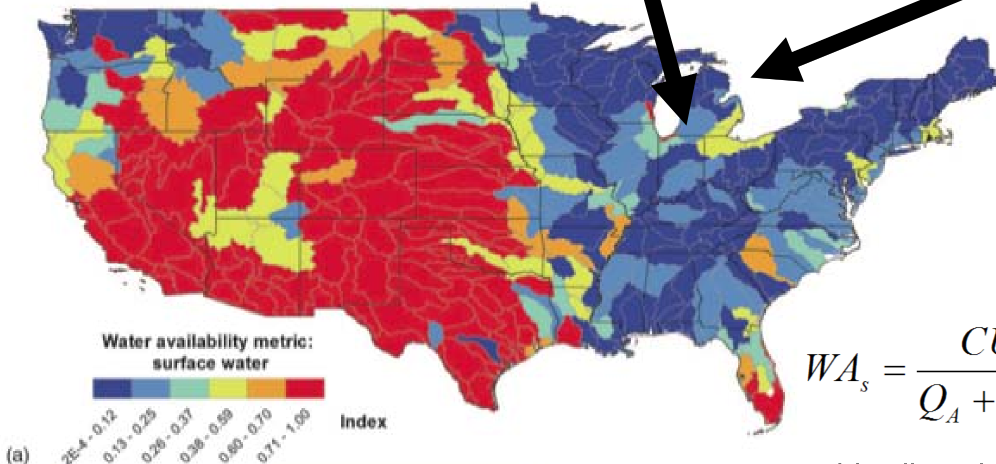
This pattern is driven by many factors; *Kumar and Singh,* 2005 found that arable land availability, not water availability drove production patterns for water embedded in international agricultural trade.

What technical advances are needed to apply Virtual Water Accounting to the Great Lakes basin?



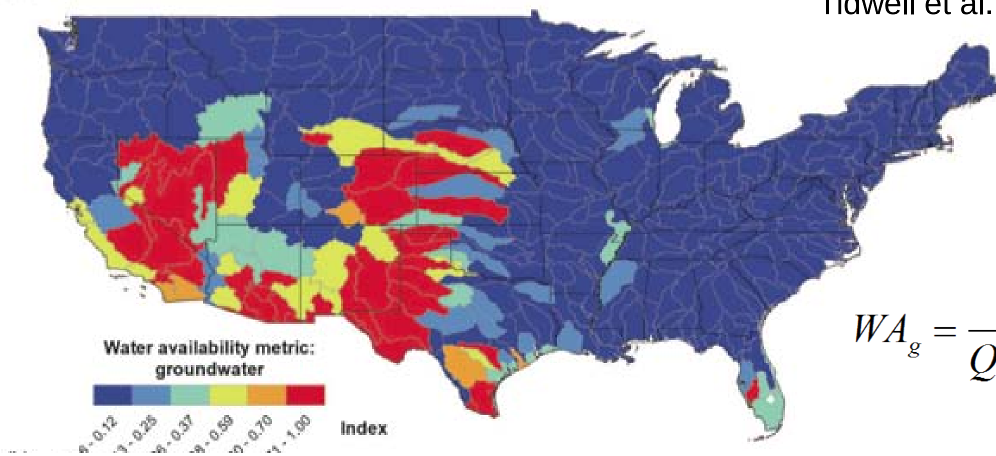


Low-flow vulnerability rankings for Great Lakes HUC-8 watersheds. For details on metric development and flow calculations, please refer to: GLEW Synthesis Report (p. 18) and Environmental Rules to Classify Basins for Sensitivity to Future Energy Development (M. Bain, p. 7).



$$WA_s = \frac{CU_w + CU_u}{Q_A + CU_w + CU_u}$$

Tidwell et al., 2012

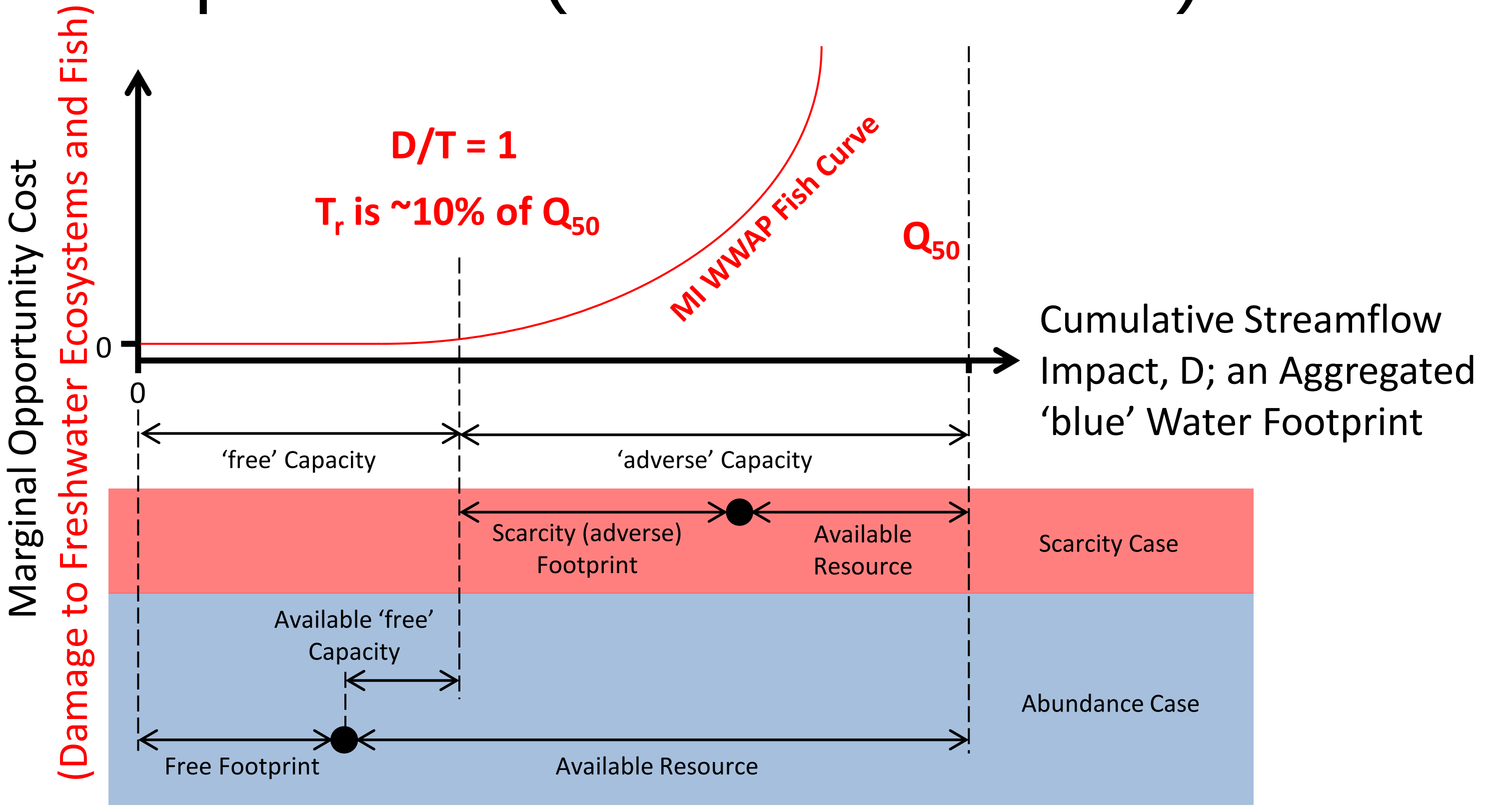


$$WA_g = \frac{P_w}{Q_B + P_w}$$

Scale of space and time is more important in a water-rich system like the Great Lakes than in the dry Southwest

Translating Water Footprints and Virtual Water into a socio-hydrological sustainability metric: Water Scarcity Footprints (LCA Midpoint Metric)

MI WWAP Fish Curve Adverse Resource Impact Explanation (ARI's/Thresholds)



Relationship between Water Withdrawals and Freshwater Ecosystem Water Scarcity Quantified at Multiple Scales for a Great Lakes Watershed

Stanley T. Mubako[1]; Benjamin L. Ruddell, M.ASCE[2]; and Alex S. Mayer, M.ASCE[3]

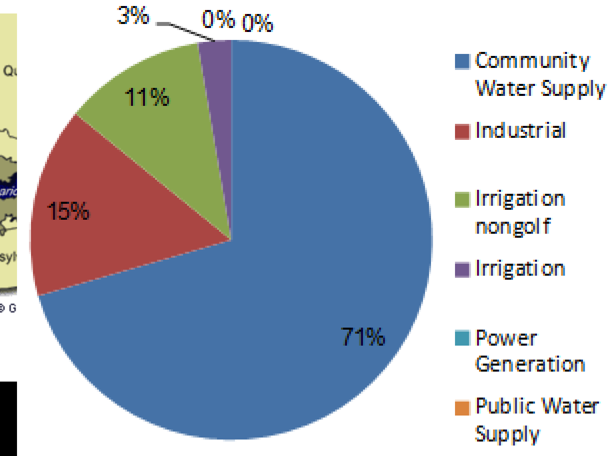
Abstract: Even in relatively water-rich regions, withdrawal and consumption of water has the potential to create instream freshwater ecosystem water scarcity, especially at seasonal and local scales. Water resource policy must balance consumptive uses of water against corresponding ecosystem impacts of flow depletion. In this study, the concept of an adverse resource impact threshold, as established by the Michigan Water Withdrawal Assessment Process, is applied in conjunction with a water use database to identify the cause, location, and scale in space and time of instream freshwater ecosystem water scarcity caused by consumptive uses of water. The study results show that there is a strong multiscalar linear relationship between freshwater consumption, adverse resource impact ecological flow thresholds, and spatial scale. On average and at the whole-watershed scale, water scarcity does not exist in this watershed, but water scarcity does occur on a localized basis, especially in the summer and at small watershed scales of less than 300 km^2, because of a combination of irrigation withdrawals, concentrated urban withdrawals, and low ecological flow thresholds. The aggregated effects of localized flow depletion also affect 800–2,000 km^2 scale catchments. Management of water scarcity in water-rich areas should therefore focus on the spatio-temporal locations where the impacts occur and where an average pattern of water abundance yields to localized scarcity, in this case during late summer months in subwatersheds smaller than 300 km^2. This analysis informs integrated water resources management approaches, contributes to a better understanding of the relationship between scale and environmental impact as water is shared among competing uses, and sheds light on the use of adverse resource impact ecological flow thresholds to define water scarcity in relatively water-rich regions. These results may be generalized to inform the implementation of the Michigan Water Withdrawal Assessment Process and similar processes throughout the Great Lakes region and in water-rich locations around the world where water is generally abundant but localized water scarcity is becoming an increasingly important issue. **DOI:** 10.1061/(ASCE)WR.1943-5452.0000374.

CE Database subject headings: Fresh water; Ecosystems; Great Lakes; Economic factors; Watersheds.

Author keywords: Freshwater ecosystem; Water withdrawals; Ecological flows; Scale; Great Lakes; Michigan water withdrawal assessment process (MI WWAP); Integrated water resources management (IWRM); Thresholds; Economic use.

J. Water Resour. Plann. Manage. 2013.139:671-681.

Kalamazoo Database



DATA SOURCE: The Michigan Water Withdrawal database, and the MI WWAP tool, are available online at: http://www.miwwat.org/

Impact Accumulation Methods

(1) For stream segments ‘C’ and processes ‘x’,

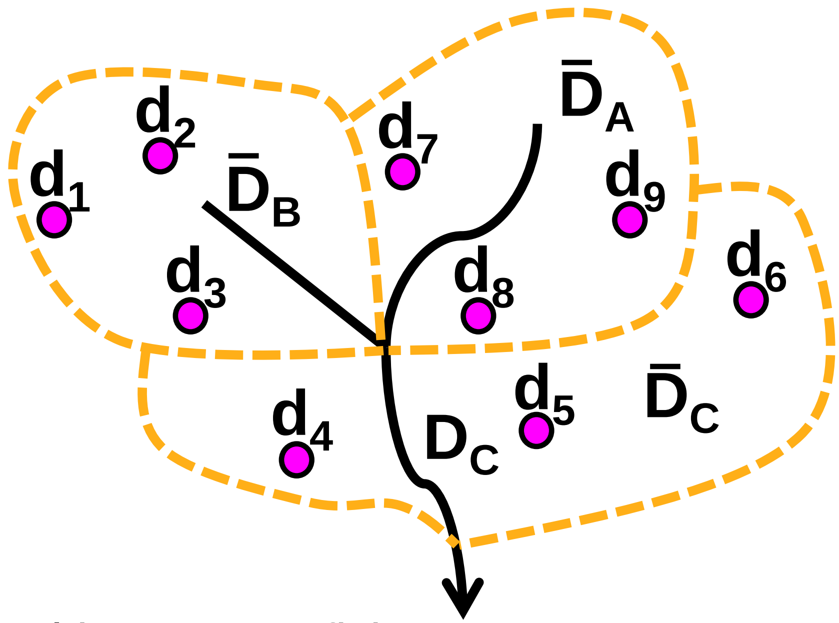
$$\bar{D}_C = \sum_{x \text{ in } C} (d_x)$$

*d_x can be negative!
(discharge from storage)

(2) To aggregate depletions,

$$D_C = \bar{D}_B + \bar{D}_A + \bar{D}_C$$

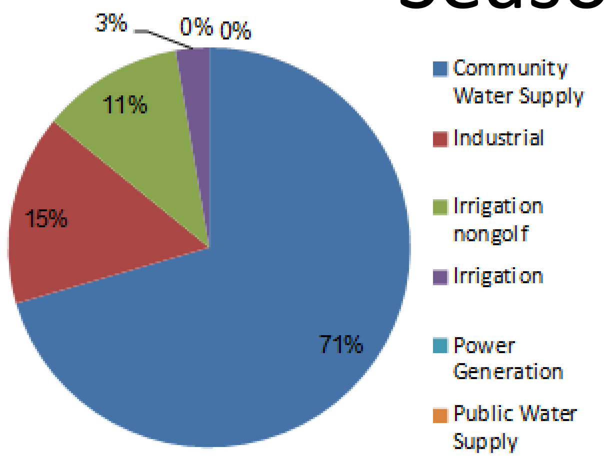
Sum over all upstream tributaries to C

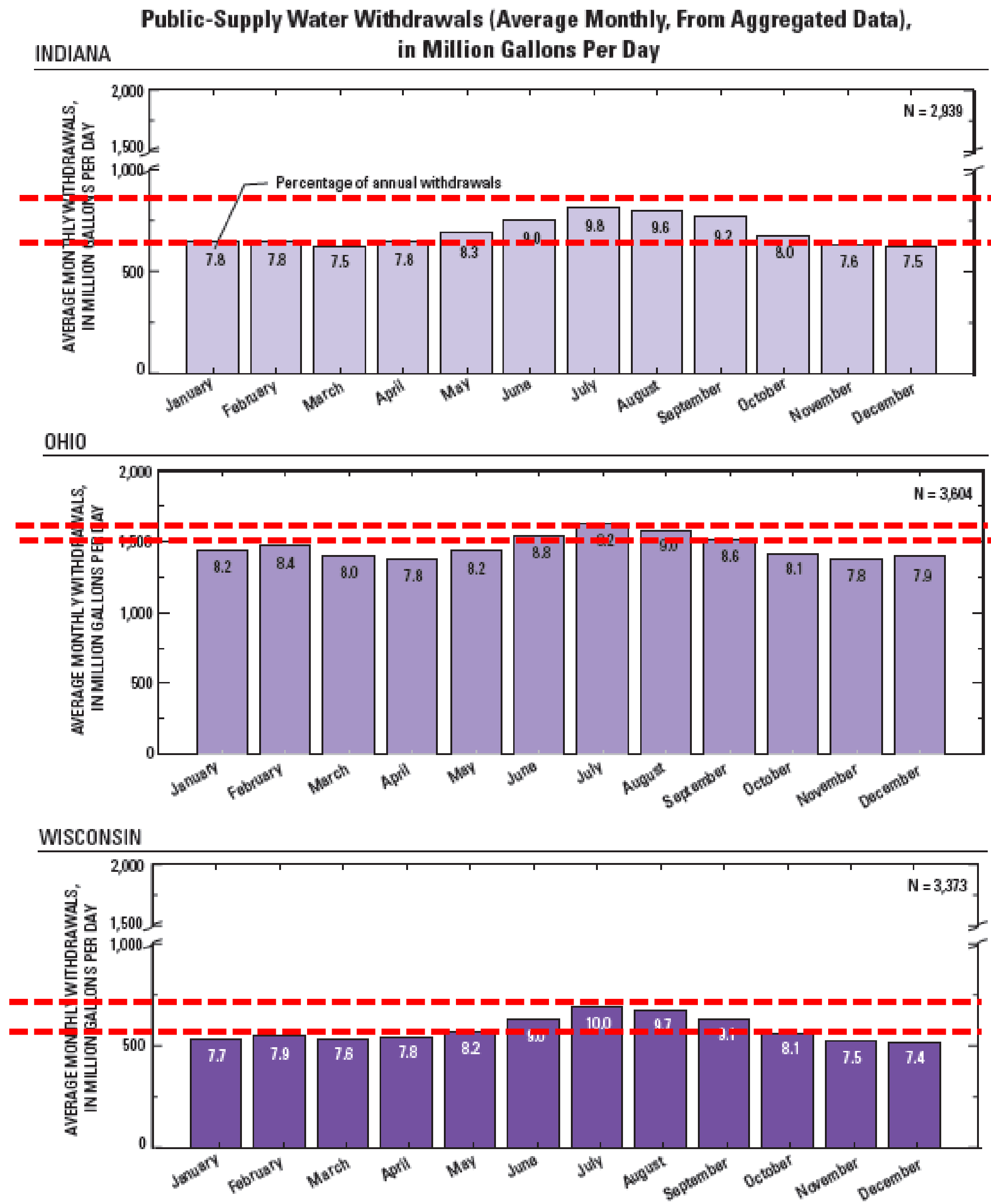


MI WWAP:

- Linked models determine water withdrawal impacts on fish populations (Steinman et al. 2011).
- Based on assumed Q_{50} median streamflow baselines for low-flow summertime months.
- Establishes ARI thresholds for summertime streamflows based on maximum allowable fish costs; these are from 1% to 13% of Q_{50}, usually 10%.

Seasonal Adjustment of Withdrawals



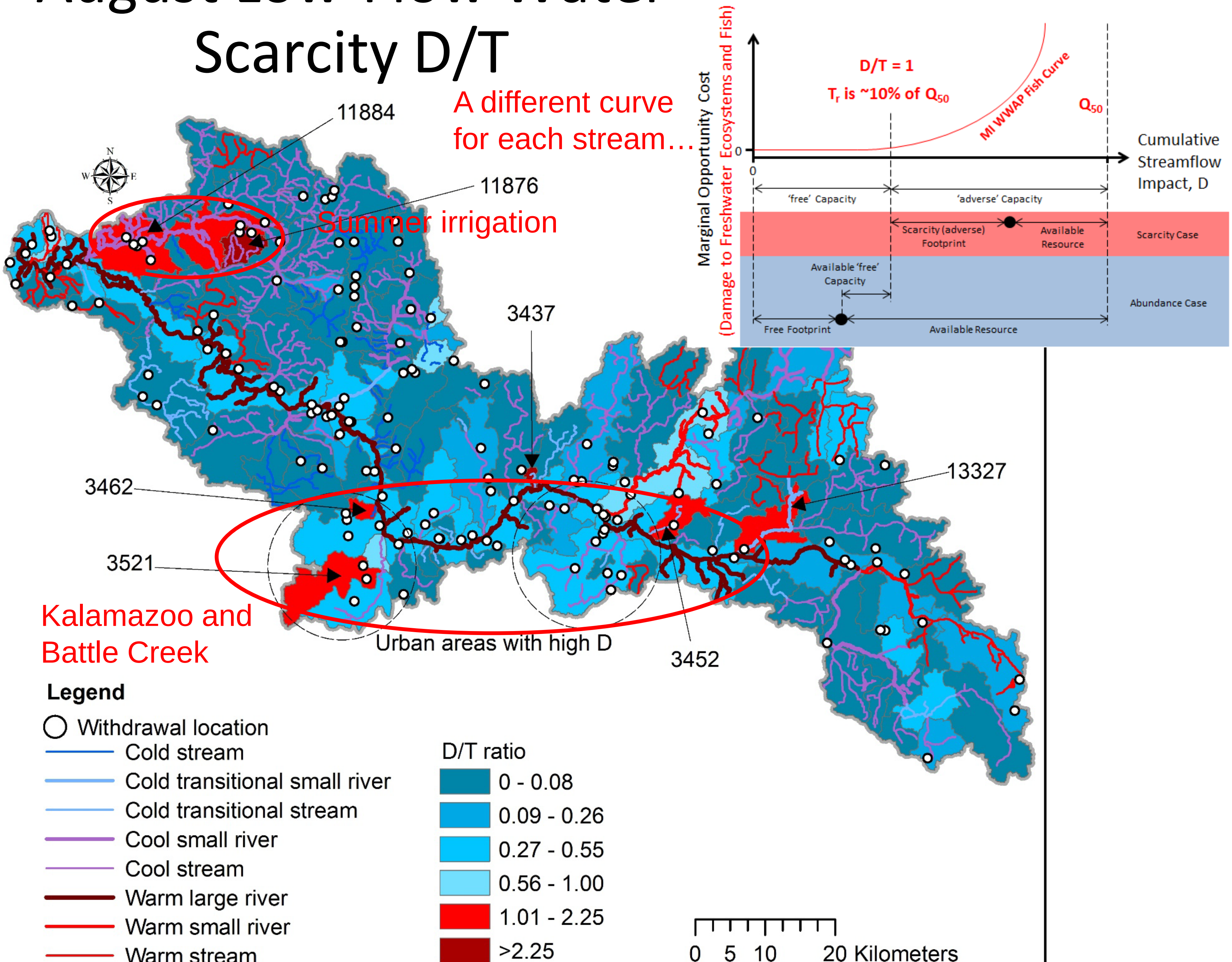


<u>Low flow month (August) adjustment factor</u> = August monthly withdrawal rate ÷ by annual average withdrawal rate taken from the Michigan Water Database

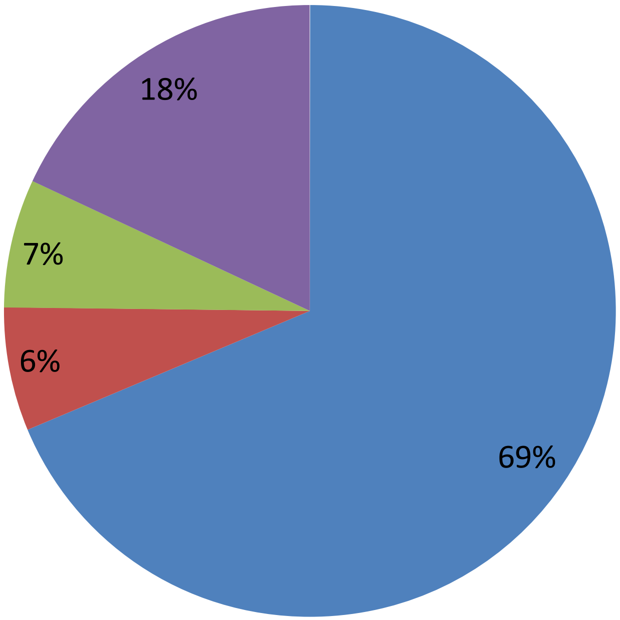
Agricultural irrigation = 3.95
Public/Community = 1.35
Industry = 1.11
Golf course irrigation = 2.6
Power generation = 1.19
Public water supply =1.14

Source: USGS, Shaffer (2009)

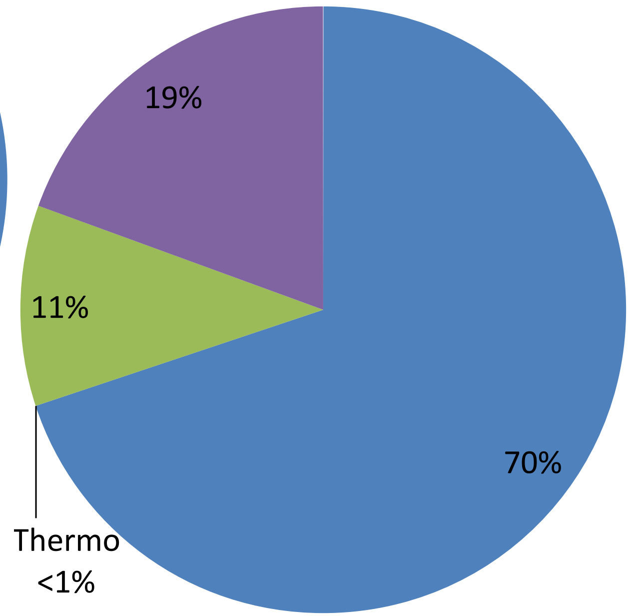
August Low-Flow Water Scarcity D/T



Annual Kalamazoo VW Imports and Exports



Total VW imports =
17 Mm^3/yr.



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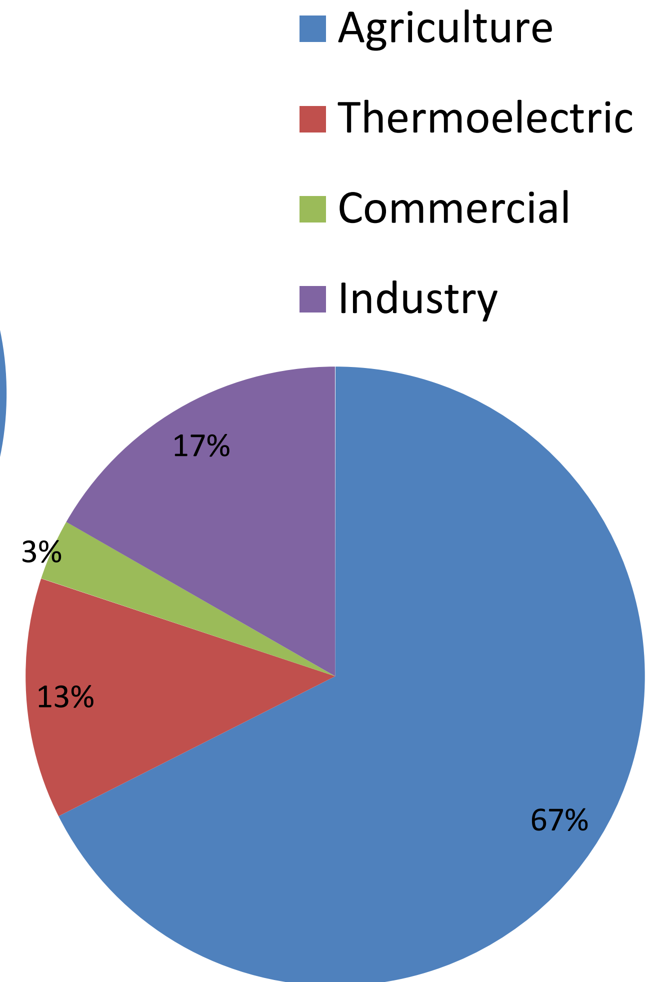
Total VW exports =
8 Mm^3/yr.

=

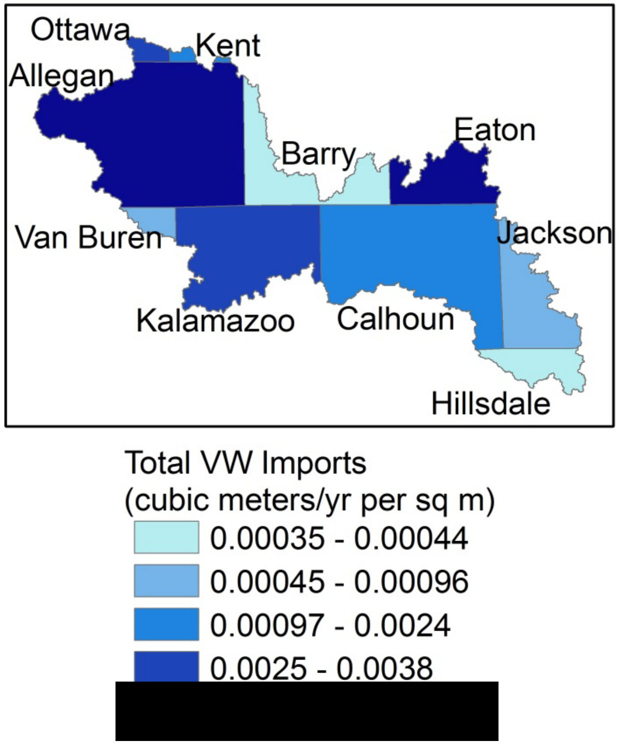


Total Net VW flow =
+ 9 Mm^3/yr.

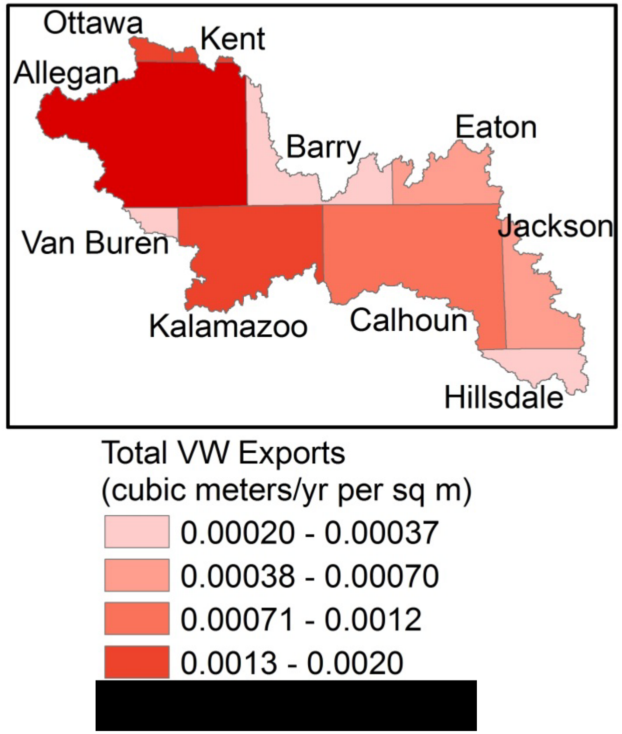
Agriculture responsible for the bulk of VW flows

Kalamazoo Watershed (HUC 8) Normalized Total Virtual Water Imports and Exports (all sectors): the 'blue' economy

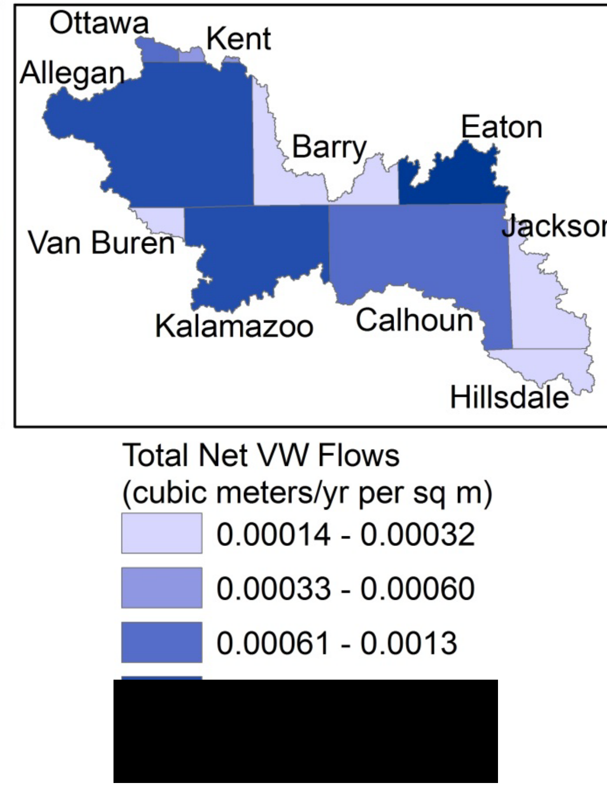
Imports



Exports

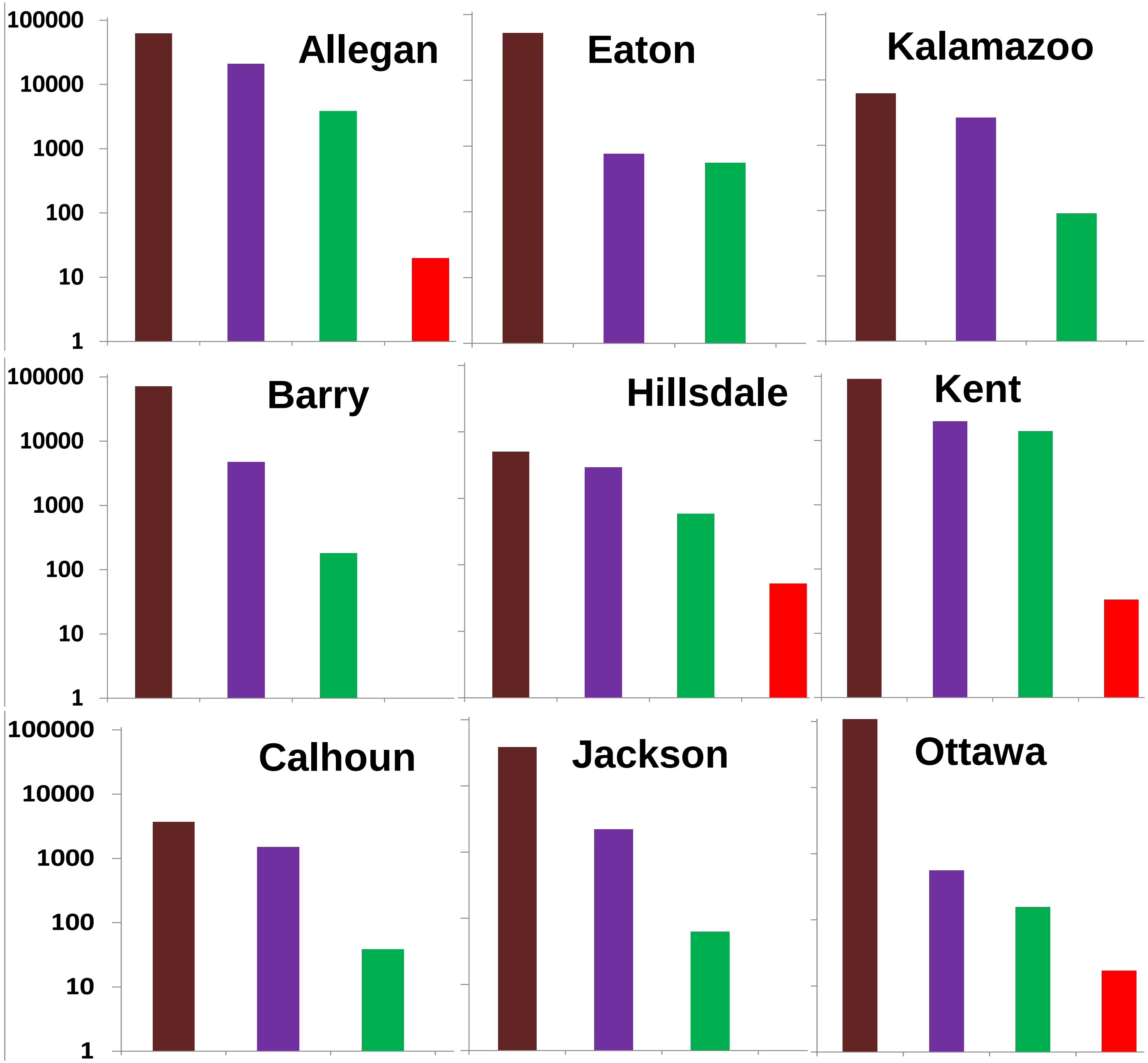


Net



Overall, the Kalamazoo watershed is a net virtual water importer

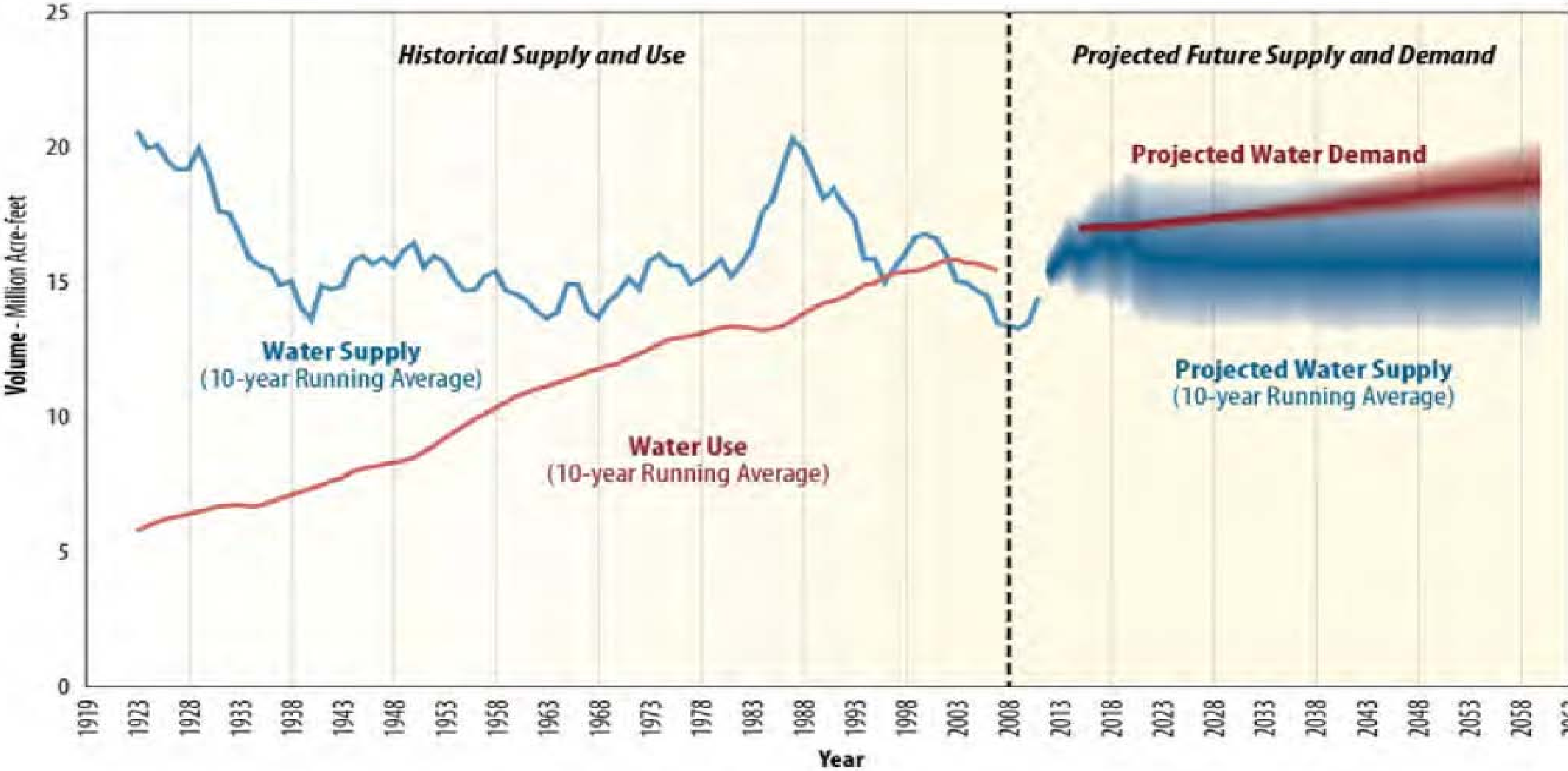
Ranked value intensities ($/m³) by county* (log scale)



Industry and Commercial sectors produce the largest economic output ($) for each m³ of water consumed

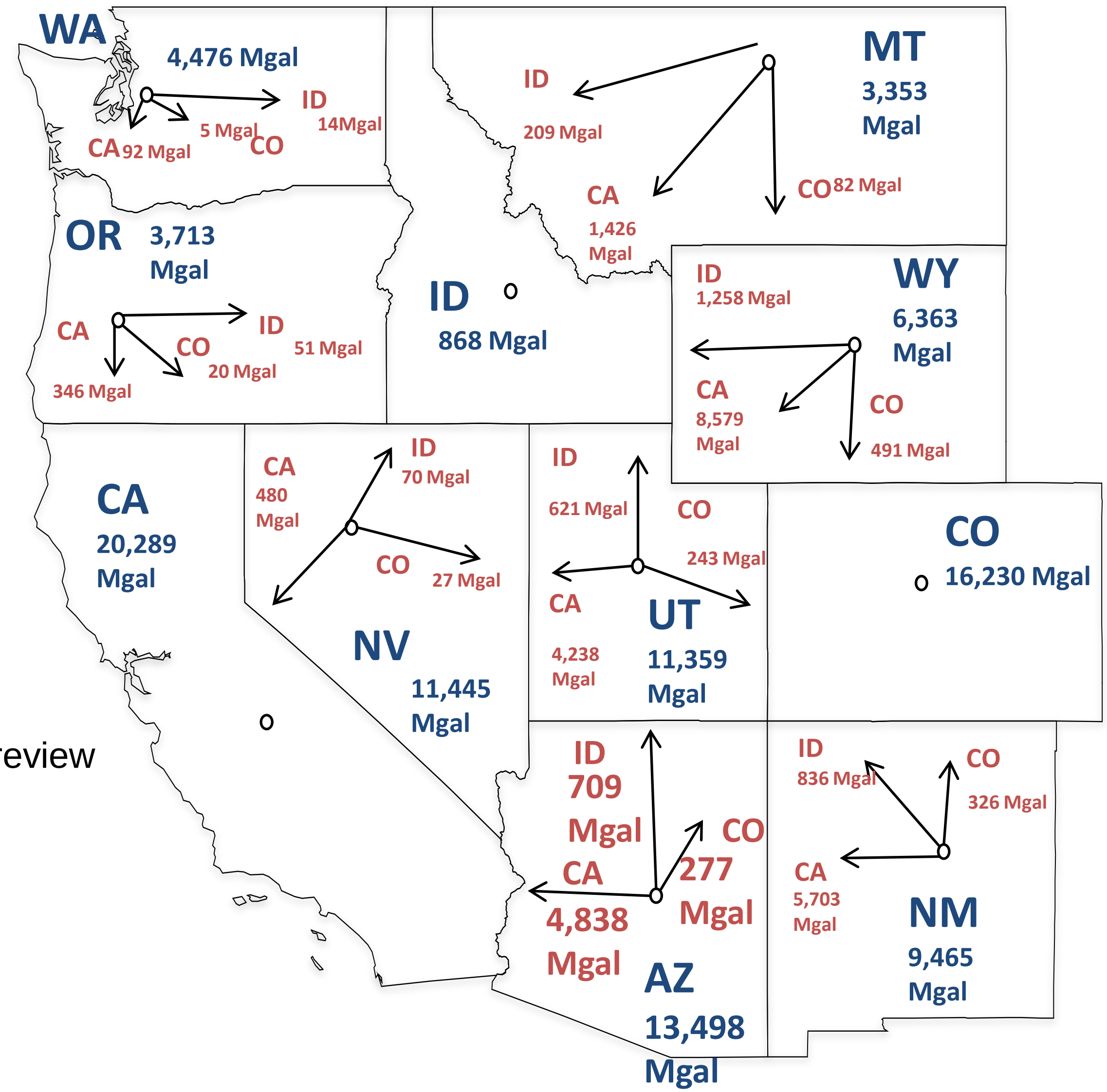
*total county area

Growing Demands and Diminishing Supplies in the Western U.S. (and in many other places)



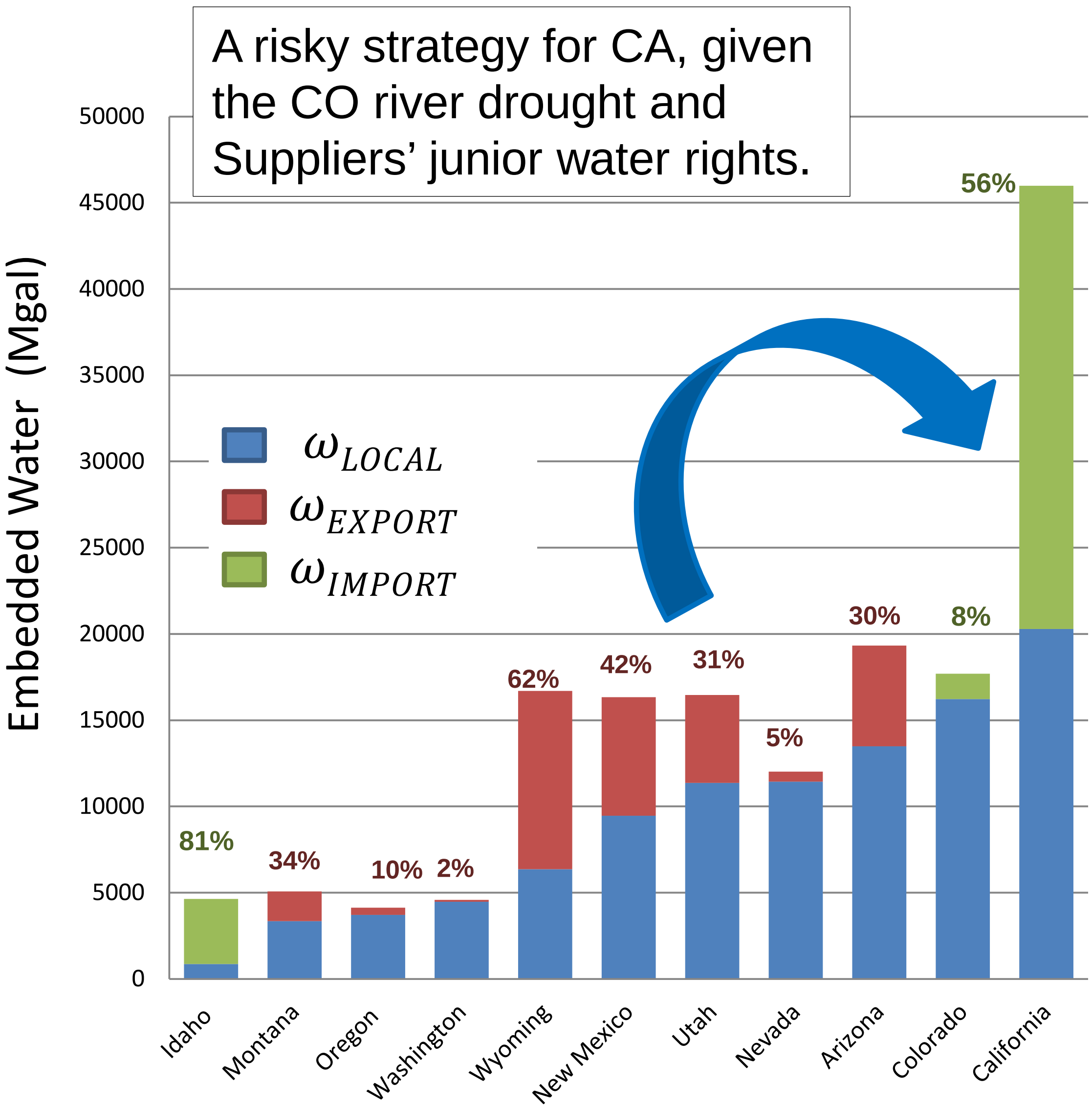
U.S. Bureau of Reclamation, 2013

Virtual Water Embedded in the Electrical Power Grid: Cities Outsourcing Water Use via Energy Import

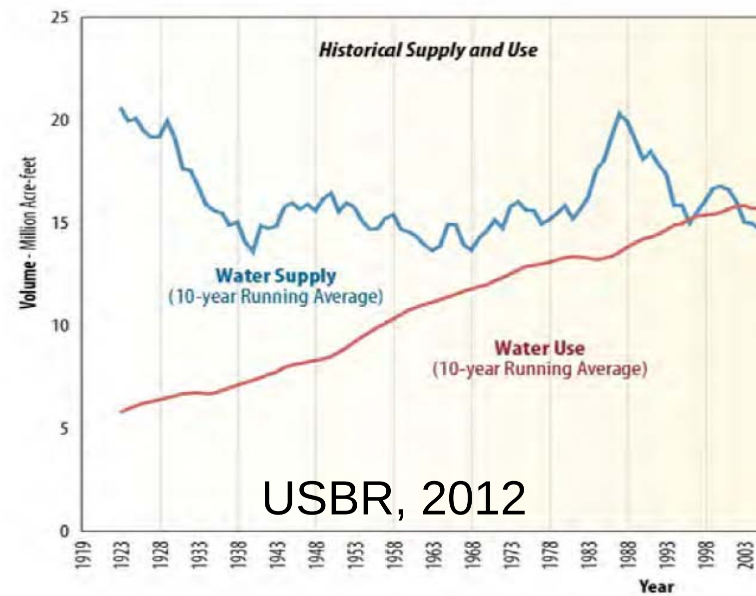


Ruddell et al., in review

A systematic shift of water impacts (and carbon emissions) from California to energy exporters like Wyoming



Martin and Ruddell [2012]



California – Net Energy Consumer

9th largest economy in the world

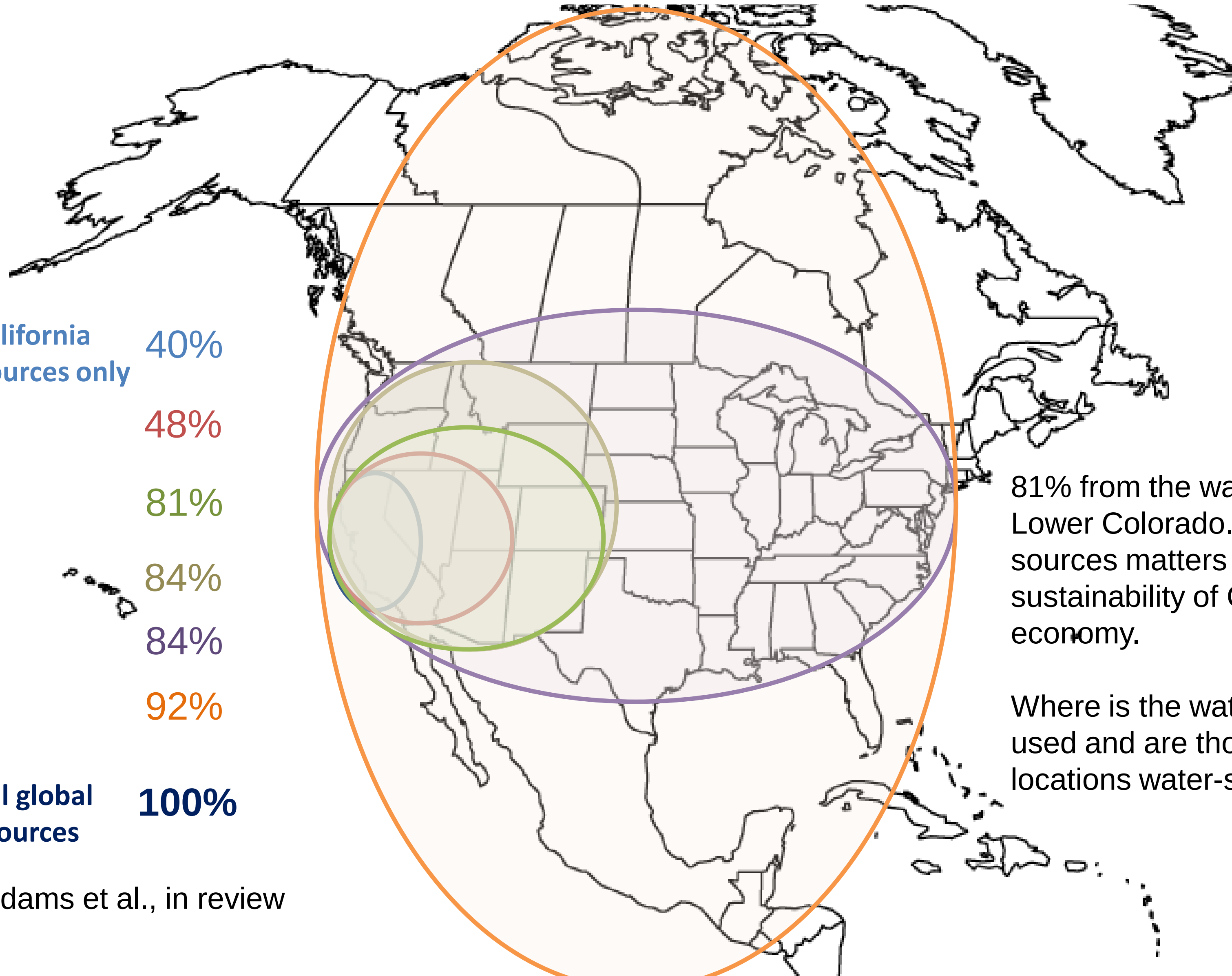
38 million people

7.8 quadrillion Btu of energy consumption in 2011

Largely urban

How does the water footprint of California's energy consumption (all types) change as the network boundaries change?

EXTERNALIZATION OF IMPACTS



Q=1 for California water resources only 40%

48%

81%

84%

84%

92%

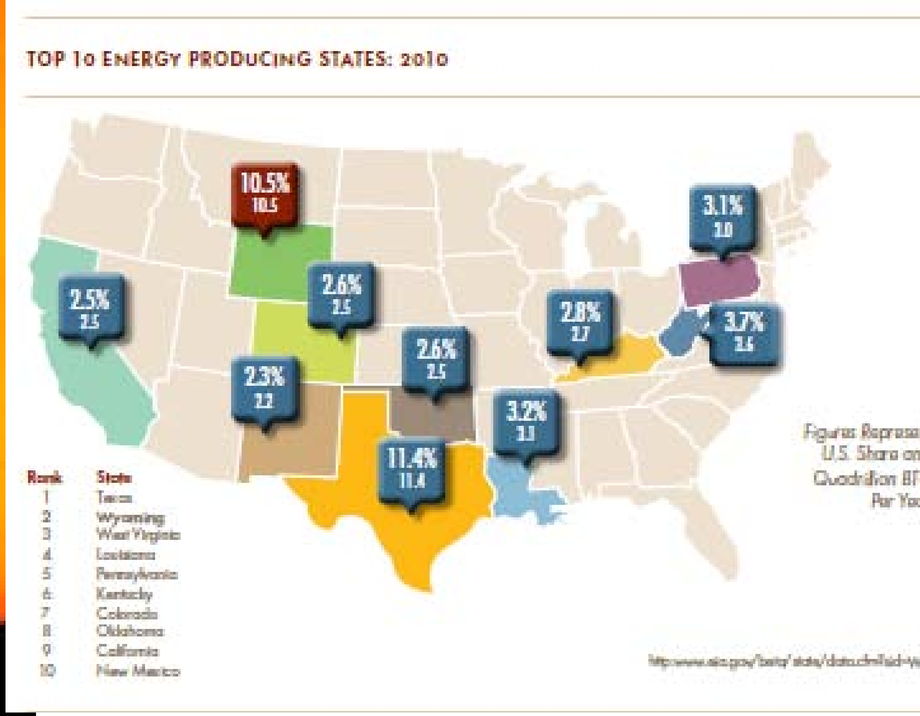
Q=1 for all global water resources **100%**

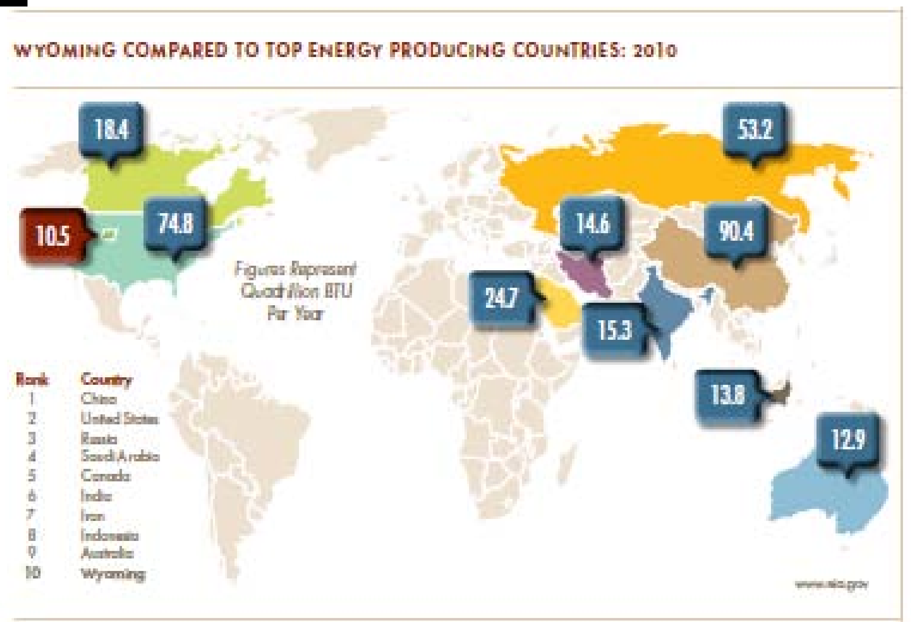
Adams et al., in review

81% from the water-scarce Lower Colorado. Location of sources matters for the sustainability of CA's urban economy.

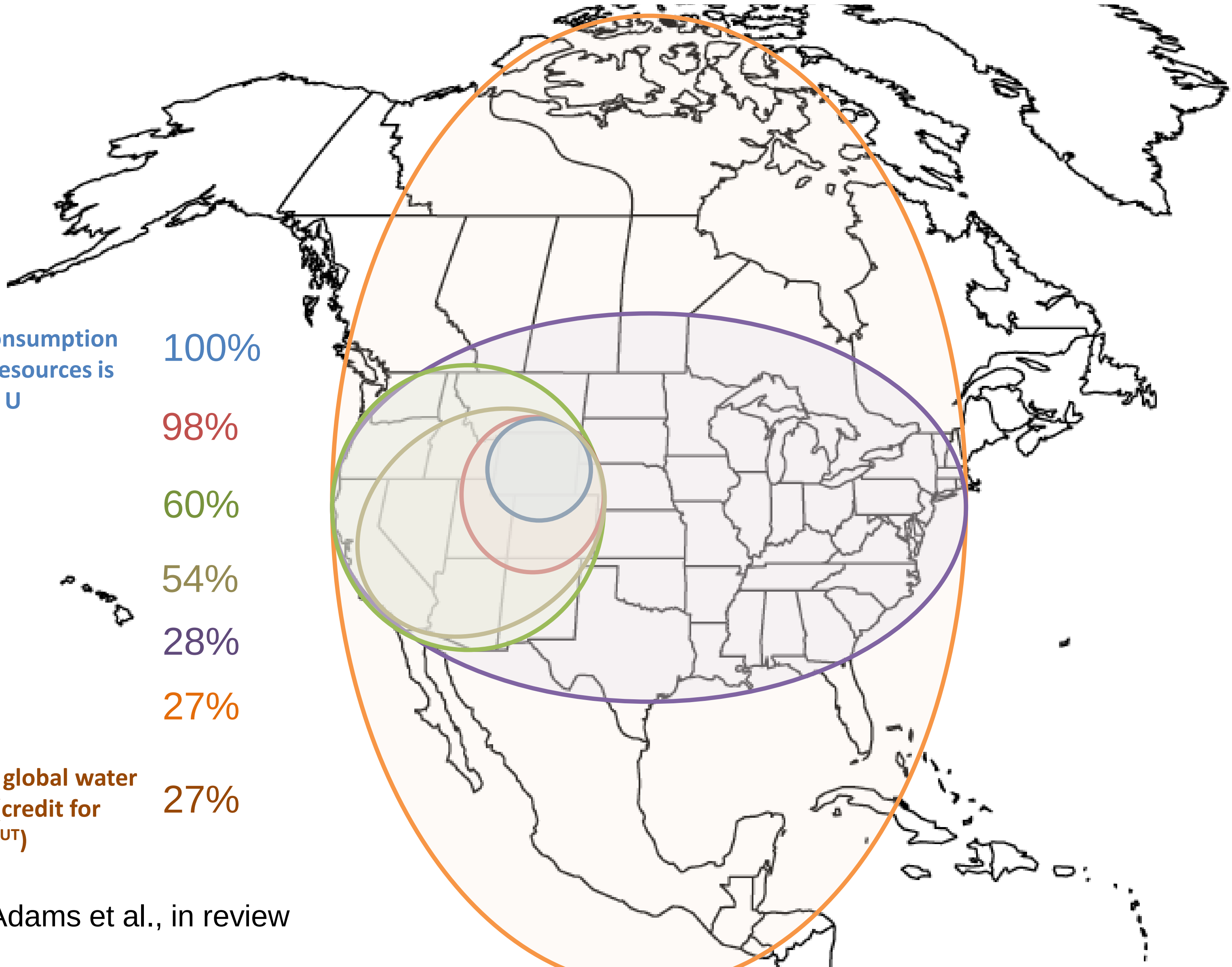
Where is the water being used and are those locations water-secure?

Wyoming – Net Energy Producer





How does the water footprint of Wyoming's energy consumption (all types) change as the network boundaries change?
INTERNALIZATION OF IMPACTS



Adams et al., in review

What Explains Virtual Water flow?

Hint: it’s not gravity…

Value Intensity (VI) quantifies relative tradeoffs and indirect valuation or equivalence of resource stock impacts translated through a multitype CNH Process Network.

$$\left(\frac{USD\$_{consumer}}{MWh_{consumer}}\right) \times \left(\frac{MWh_{producer}}{gal_{producer}}\right) = \left(\frac{USD\$_{consumer}}{gal_{producer}}\right)$$

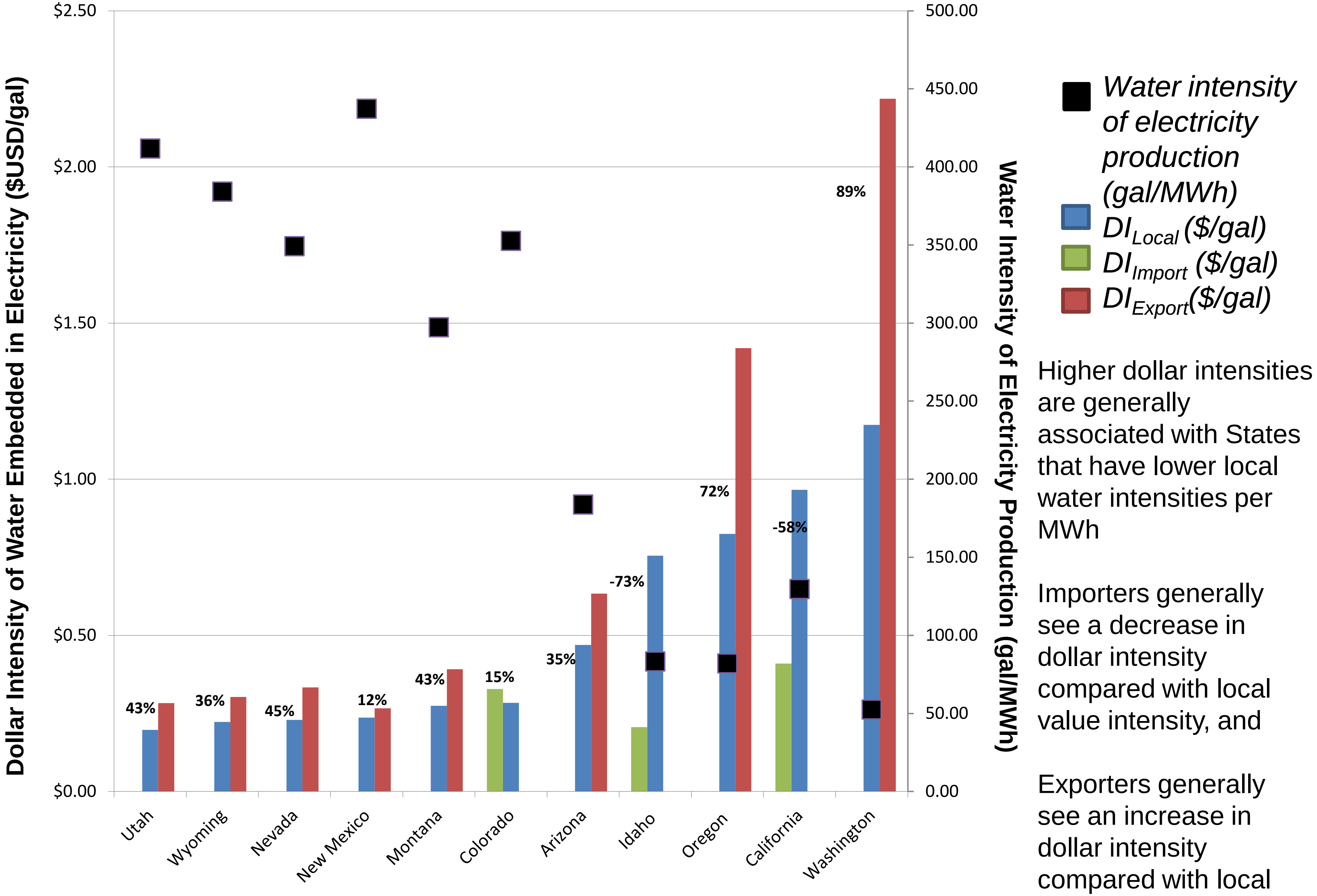
Retail electricity price. Function of the economic market.

Water efficiency of electricity generation. Function of the current technology.

Dollar intensity of the embedded water; indirect valuation; a shadow price IF no profit and water is the only input

(Example: via Market trade in Electrical Power)

(Virtual) water flows uphill toward value, in this case $$$



Martin and Ruddell, 2012

Higher dollar intensities are generally associated with States that have lower local water intensities per MWh

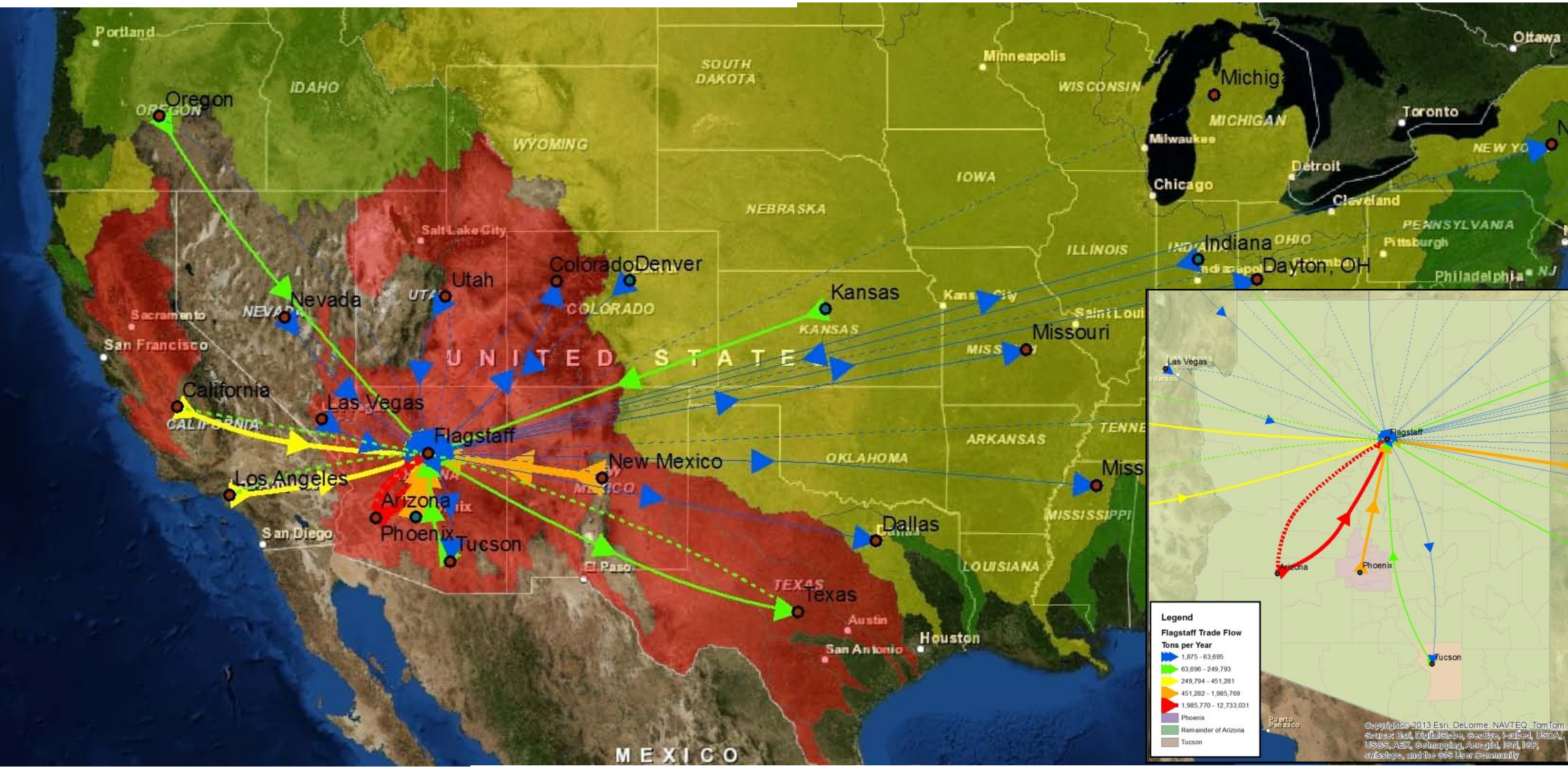
Importers generally see a decrease in dollar intensity compared with local value intensity, and

Exporters generally see an increase in dollar intensity compared with local value intensity

Trade Network for Flagstaff, AZ

Cities are the hubs of the economic network and they outsource most of their water use

Local & Regional Trade dwarfs international

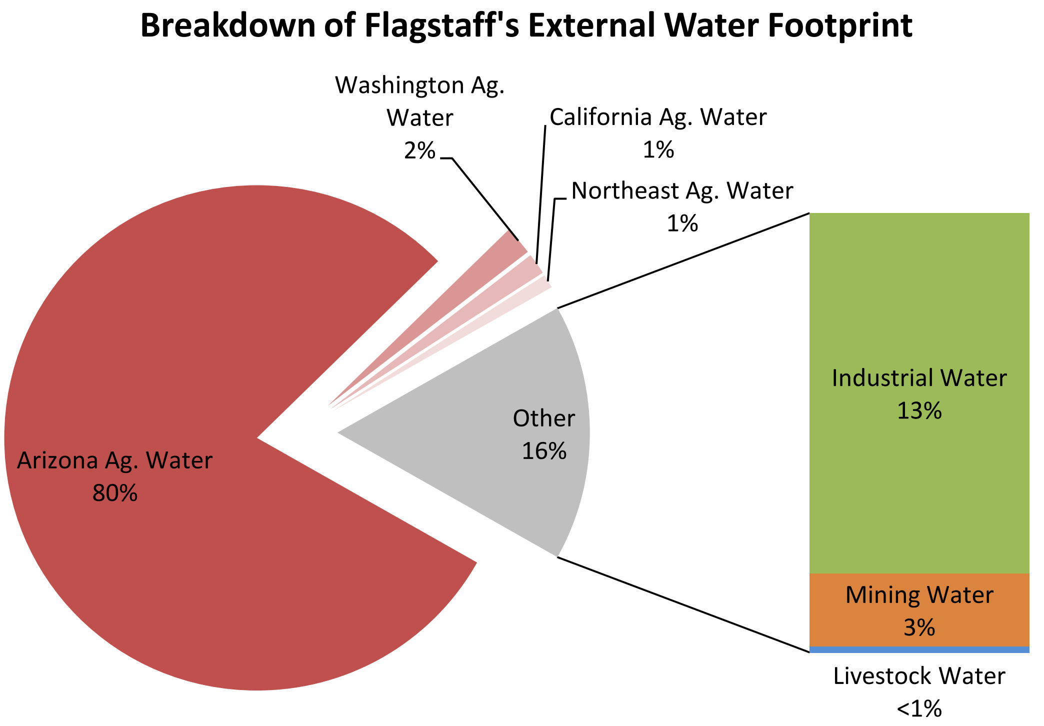


Network based on the 2007 US Commodity Flow Survey; watershed color indicates water stress (Hoekstra and Mekonnen, 2011)

- Interstate trade is primarily West to East, indicating a flow of embedded water from drier to wetter areas (except KS and OR)
- Local trade is primarily imports of raw materials and agricultural

Flagstaff Virtual Water Imports

State	Water Import ac-ft/year	% of Total
AZ	50,185	93.0%
WA	1,103	2.0%
CA	998	1.8%
TX	526	1.0%
LA	410	0.8%
SC	238	0.4%
IN	130	0.2%
OH	66	0.1%
MI	60	0.1%
CO	59	0.1%
OR	53	0.1%
IL	24	0.0%
NV	24	0.0%
TN	22	0.0%
NM	19	0.0%
WV	14	0.0%
GA	14	0.0%
NY	4	0.0%
PA	4	0.0%
MO	3	0.0%
WI	3	0.0%
MA	2	0.0%
MN	2	0.0%
UT	2	0.0%
KS	1	0.0%
Total	53,966	



Economy Sector	Import Value (2007 $)	Embedded Water (acre-feet)	Embedded Water Value ($/gallon)
Primary	$875,432,388	48,559	$0.06
Secondary	$1,327,485,470	4,937	$0.83
Tertiary	$487,343,881	501	$2.99

Value Intensity Drives Urban Water Metabolism

External Origin

	Value ($)	Tons	Water Consumption (ac-ft)	$/ton	$/gallon
Primary	$28,057,163	29,685	48,591	$945.15	$0.00
Secondary	$740,299,473	299,504	5,783	$2,471.75	$0.39
Tertiary	$533,070,436	227,634	1,110	$2,341.79	$1.47
Quaternary	$641,838,287	0	734		$2.68
Total	$1,943,265,359	556,824	56,217	$3,489.91	$0.11

Local Origin

	Value ($)	Tons	Water Consumption (ac-ft)	$/ton	$/gallon
Primary	$7,066,094	28,428	96	$248.56	$0.23
Secondary	$394,272,217	368,843	776	$1,068.94	$1.56
Tertiary	$2,102,894,562	63,895	4,210	$32,911.73	$1.53
Quaternary	$1,292,832,669	0	3,884		$1.02
Total	$3,797,065,542	461,166	8,950	$8,233.62	[illegible]

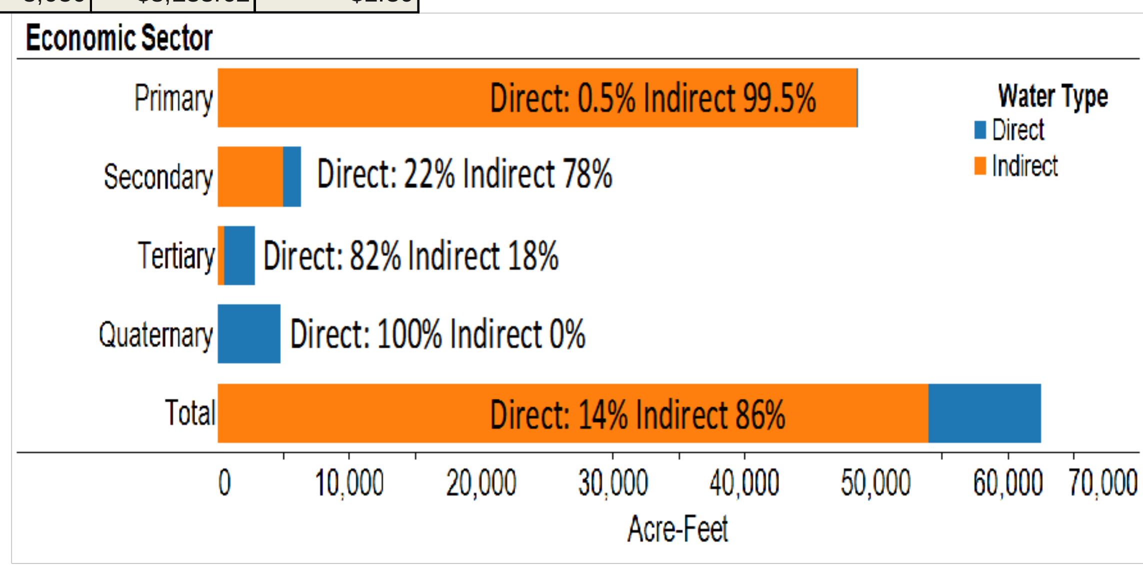
Most value is associated with the higher economic levels on which cities specialize.

Flagstaff, a small city, is in the middle of the 'water value chain', peaking in Tertiary

Sectors: Kenessey, 1987

Cities drive low-value water resource impacts indirectly, by outsourcing them through the trade network, while focusing on high-value water resource impacts.

Rushforth et al., in review



Conclusions

- Water scarcity is caused by, and can be fixed by, the economy
- Wealthy cities, and their trade networks, are THE key.
- Boundaries matter; political and hydrological.
- MOST water-heavy energy and food production is outsourced, making the Kalamazoo a net importer
- Hotspots exist at smaller space-time scales in water-rich systems like the Great Lakes, so we have a harder technical problem linking VW trade to ecosystems here.
- Ongoing work: In the Kalamazoo and water-rich watersheds, we are linking impacts on ecosystem flow 'hotspots' to economic value and to virtual water trade…
- Do we want to be California or Wyoming? Currently, the Great Lakes are more like California.

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(views expressed are those of the authors, and not necessarily the National Science Foundation)

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GLPFund

Sandia National Laboratories

CAP LTER

ASU Global Institute of Sustainability

Walton Sustainability Solutions Initiatives

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