Human populations in river corridors and

[water quality, migration pressures, scarcity, food security, adaptation and resilience....]

humans + hydrology

James W. Jawitz
University of Florida, USA

[new partnership with UFZ + TU Dresden]
1. disciplinary interfaces
   hydrology + humans

2. cities + river networks
   scale, scope, perspective

3. transferable theories
   networks, trajectories, heterogeneity
1. interfaces:

hyphenated hydrology

McCurley and Jawitz [ongoing], Multidisciplinary evolution of water resource science
- WRR article titles 1965-2015
- evolution of changing interfaces
hydrology + [geology, atmospheric sciences]  
*disciplinary foundations, 1990s re-alignment*
hydrology + [contaminants, climate, ecology, social]

disciplinary extensions, 1990s new directions (?)

2012, Sivapalan et al.

2008, Ecohydrology
2. cities + river networks

scale, scope, perspective

Padowski and Jawitz [2012]. Water availability and vulnerability of 225 large cities in the United States, *WRR*

Padowski et al. [in review]. Overcoming urban water insecurity through infrastructure and institutions

Fang and Jawitz [in review]. Human population distribution in the conterminous United States: High resolution reconstruction 1790-2010
hydrologists

rivers

log A, L, Q, etc

stream order
economists/geographers

log size

log rank

cities
humans + hydrology
humans + hydrology

urban water availability? local + captured

water yield?

\[ Q_{\text{catchment}} = P - E \]

\[ Q_{\text{city}} = [P - E]_{\text{local}} + Q_{\text{river}} + Q_{\text{wells}} + Q_{\text{reservoirs}} \]
humans + hydrology

captured water includes water transfers

\[ Q_{\text{city}} = (P - E)_{\text{local}} + Q_{\text{river}} + Q_{\text{wells}} + Q_{\text{reservoirs}} \]
citysheds not watersheds [scale]

US cities capture water to overcome natural scarcity

Padowski and Jawitz [2012]. Water availability and vulnerability of 225 large cities in the United States, WRR
urban water management institutions [scope]
three factors: delivery continuity / source portfolio / regulatory system

<table>
<thead>
<tr>
<th>Assessment Metric</th>
<th>US Cities</th>
<th>African Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Delivery Capacity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent of non-revenue water (&lt;10%)</td>
<td>52%</td>
<td>2%</td>
</tr>
<tr>
<td>Percent of connections metered (&gt;50%)</td>
<td>94%</td>
<td>41%</td>
</tr>
<tr>
<td>Population with access to water (&gt;50%)</td>
<td>100%</td>
<td>62%</td>
</tr>
<tr>
<td>Continuity of service (&gt;12 hrs/day)</td>
<td>100%</td>
<td>59%</td>
</tr>
<tr>
<td><strong>Supply Source</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uses captured (distant) sources</td>
<td>40%</td>
<td>55%</td>
</tr>
<tr>
<td>Uses captured (distant) and local (near) sources</td>
<td>22%</td>
<td>24%</td>
</tr>
<tr>
<td>Supplies come from more than one source</td>
<td>66%</td>
<td>79%</td>
</tr>
<tr>
<td>Supplies come from more than one source type</td>
<td>38%</td>
<td>67%</td>
</tr>
<tr>
<td><strong>Regulatory Complexity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban-urban strategies (e.g. co-manage urban source)</td>
<td>30%</td>
<td>0%</td>
</tr>
<tr>
<td>Urban-rural strategies (e.g. regional water provider)</td>
<td>14%</td>
<td>45%</td>
</tr>
<tr>
<td>Has mechanisms for GW management</td>
<td>60%</td>
<td>47%</td>
</tr>
<tr>
<td>Has mechanisms for SW management</td>
<td>78%</td>
<td>62%</td>
</tr>
</tbody>
</table>
US cities (n=60) have more-complex water management systems than African cities (n=48)

US = 6.9 ± 2.2
AF = 5.4 ± 2.4

Padowski et al. [in review]. Overcoming urban water insecurity through infrastructure and institutions
heterogeneous socioeconomic systems

urban water supply institution complexity correlates to natural availability/scarcity

Padowski et al. [in review]. Overcoming urban water insecurity through infrastructure and institutions
humans + hydrology
migration + economic development

frontier

intensifying

industrial

post-industrial
3. cities + rivers: transferable theories

networks, trajectories, heterogeneity

Fang and Jawitz [ongoing]. Are we getting farther from water?

Fang et al. [ongoing]. Global human population distributions in river corridors

Westphal et al. [ongoing]. Water quality trajectories in German catchments
cities + rivers: heterogeneity

Fang and Jawitz [in review]. Human population distribution in the conterminous United States: High resolution reconstruction 1790-2010
theory of importance of water for human settlements

*landscape heterogeneity, river networks, technology transitions, economic market potential* ...

**Hypotheses**

Relative importance of proximity to

1) rivers

2) groundwater

![Graph 1](Time)

![Graph 2](Time)
Population Density overlying **Groundwater** Basins

<table>
<thead>
<tr>
<th>Aquifer type, Recharge (mm/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major aquifers, ≥300</td>
</tr>
<tr>
<td>Major aquifers, 100-300</td>
</tr>
<tr>
<td>Complex aquifers, 100-300</td>
</tr>
<tr>
<td>Local &amp; shallow aquifers, ≥100</td>
</tr>
<tr>
<td>Complex aquifers, 20-100</td>
</tr>
<tr>
<td>Major aquifers, 20-100</td>
</tr>
<tr>
<td>Local &amp; shallow aquifers, &lt;100</td>
</tr>
<tr>
<td>Major aquifers, 2-20</td>
</tr>
<tr>
<td>Major aquifers, &lt;2</td>
</tr>
<tr>
<td>Complex aquifers, &lt;20</td>
</tr>
</tbody>
</table>

Mean population density

Decade

1790, 1840, 1890, 1940, 1990
theory of importance of water for human settlements

*landscape heterogeneity, river networks, technology transitions, economic market potential* ...

![Graph showing normalized population density vs. distance to major rivers](image)

- Frontier
- Towns
- Cities

Distance to **major** rivers

Post-industrial trends?
Population Density vs. Distance to Rivers \((\geq 4^{th} \text{ order})\)
human distance to water: 1890 vs. 1990

regional differences related settlement history

HU1: New England
HU3: South Atlantic-Gulf
HU15: Lower Colorado

Long settlement history
Groundwater richness
frontier to city + physical scarcity

Population density (persons/km²)
Distance to water (km)
Distance to water (km)
Distance to water (km)
transferable framework for cities and river networks

**geomorphic effect on human activities**

1) Geomorphic Width Function, $GW(x)$:

$$
\int_{0}^{D_{\text{max}}} GW(x)dx = A
$$

2) Demographic Width Function, $DW(x)$:

$$
\int_{0}^{D_{\text{max}}} DW(x)dx = HP
$$

Where, $A$ is river basin area, $HP$ is total population of river basin, $D_{\text{max}}$ is the longest distance to the Outlet ($0 \leq x \leq D_{\text{max}}$).
1) Demographic Width Function $DW(x)$ vs. Geomorphic Width Function $GW(x)$

Human activity intensity is stronger close to the outlet.

2) Human Activity Intensity vs. Distance to Outlet
North American 6th-order basins
humans + hydrology

**impact trajectories**

impacts

alternate possible future trajectories

historical trajectory

economic development
cities + river corridors + water quality

transferable theories, trajectories, networks

water supply vs water quality
PLAN vs PLAN-B

Population
Land use
Attenuation
Natural buffering

Basin scale
humans + hydrology

*networked water quality impact trajectories*

impacts

economic development
in conclusion

• disciplinary interfaces and transitions
  quantity to quality (1980s-1990s)
  water quality to ecosystem health (2000s)
  humanistic hydrology (2010s)

• cities and river networks
  watershed to cityshed [scale]
  physical + socioeconomic systems [scope]

• network theory perspectives
  long-view trajectories with theoretical foundations, which allow transferable application to [water quality, human migrations, technology transitions...]

[new partnership with UFZ and TU Dresden]
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