The Economics of Groundwater Governance Institutions Across the Globe

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Groundwater: A Global Problem?

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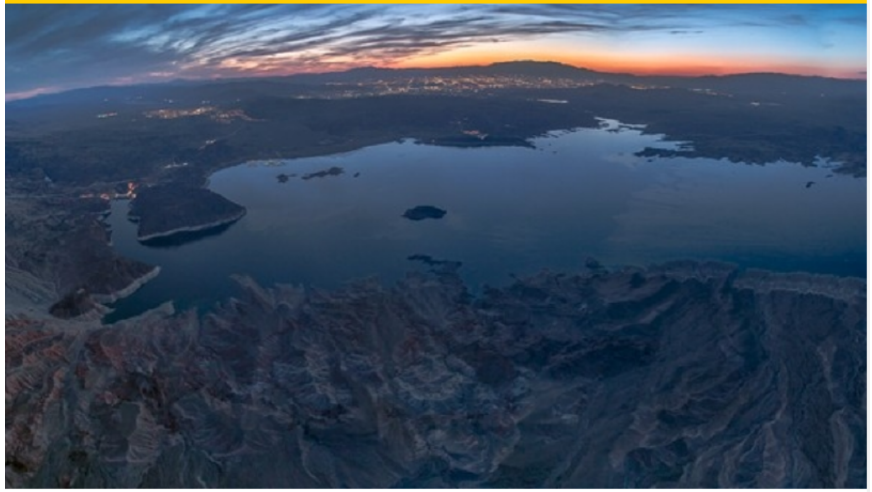

In ten years, the Colorado River Basin has lost the equivalent of two Lake Meads, the largest reservoir in the U.S., pictured here at dusk with Las Vegas in the background.

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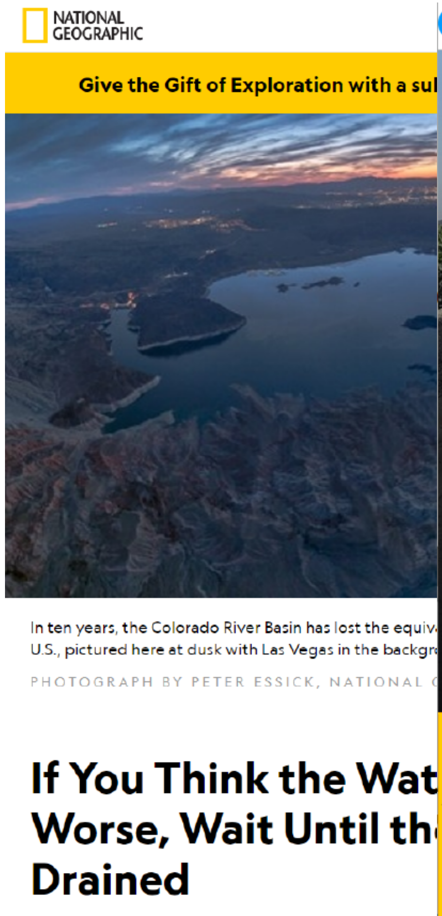
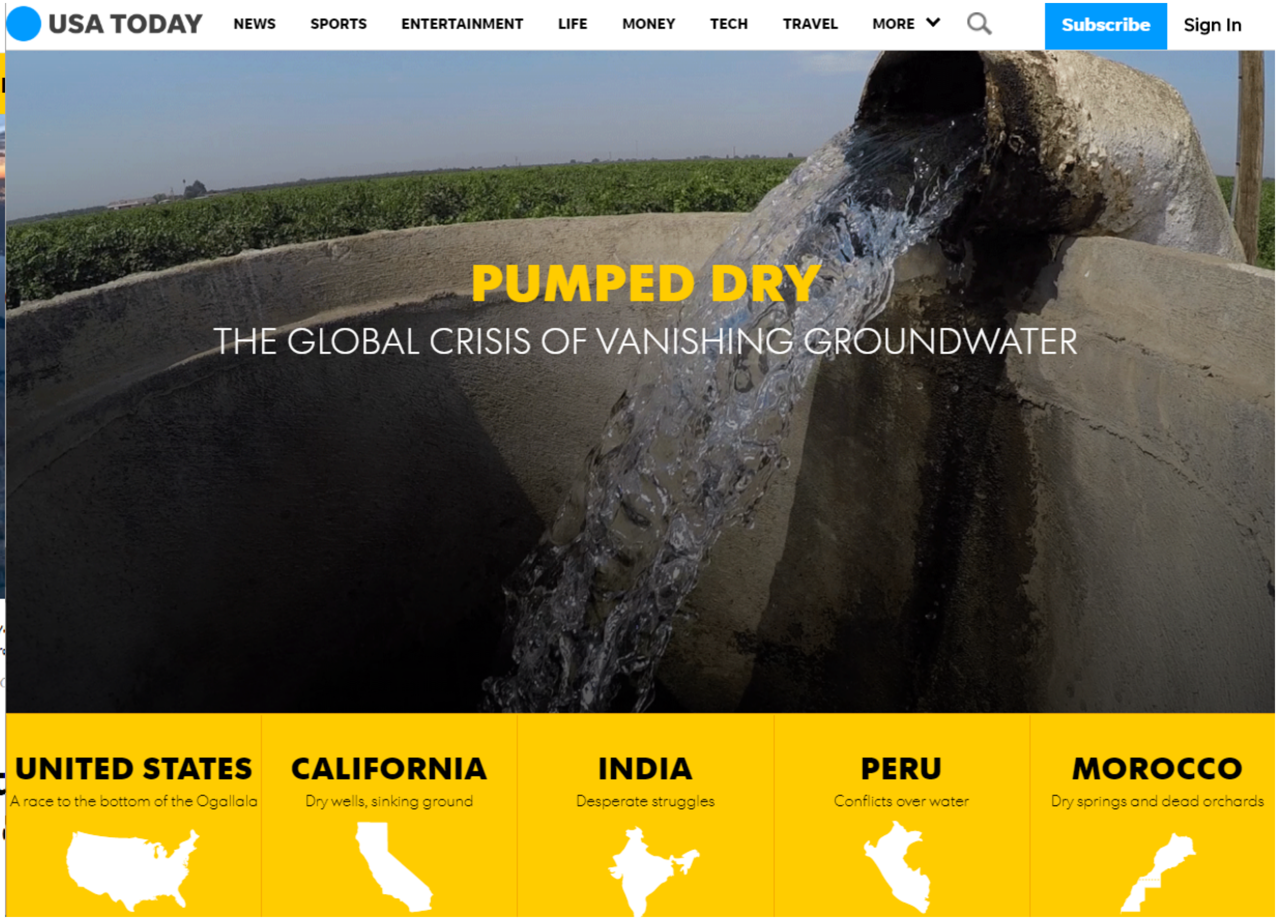
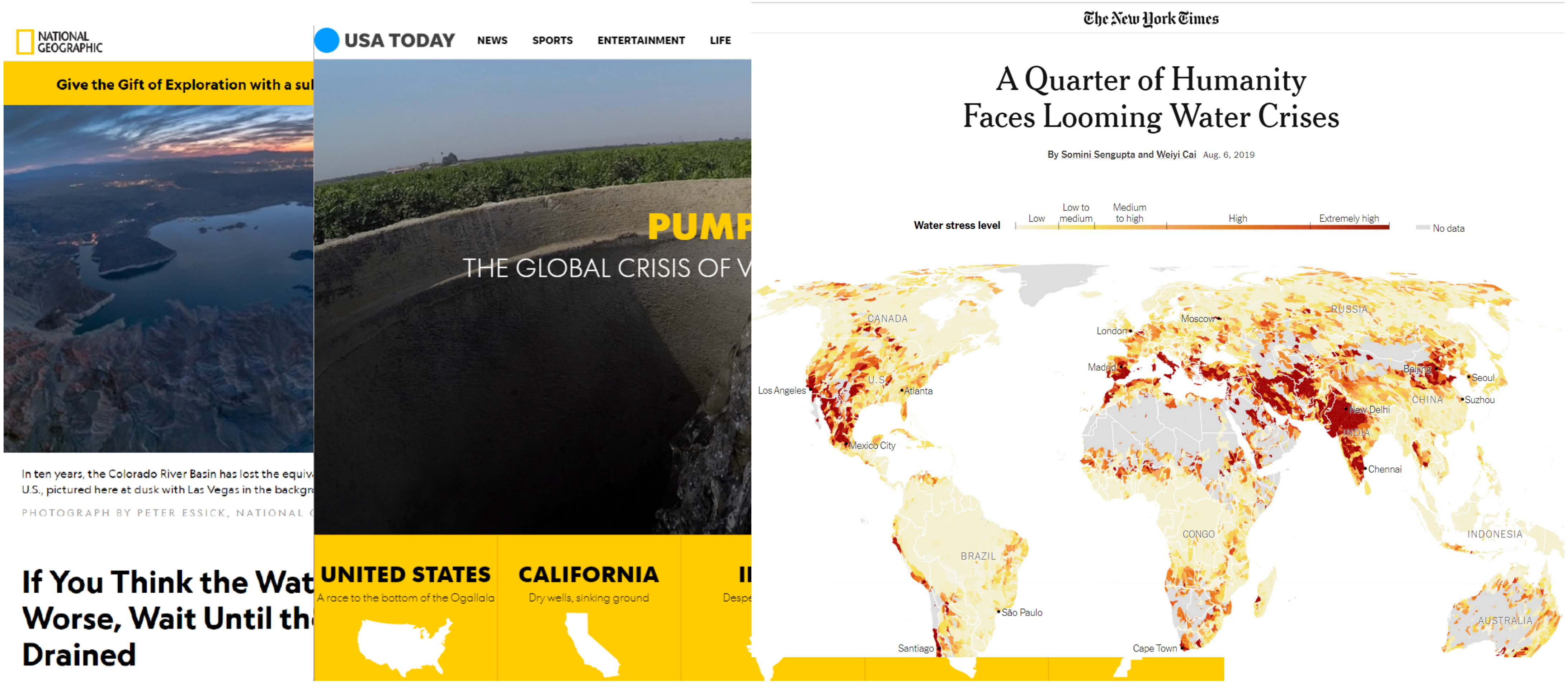
If You Think the Water Crisis Can't Get Worse, Wait Until the Aquifers Are Drained

Groundwater: A Global Problem?





Groundwater: A Global Problem?



Stylized Facts: Economics and Groundwater

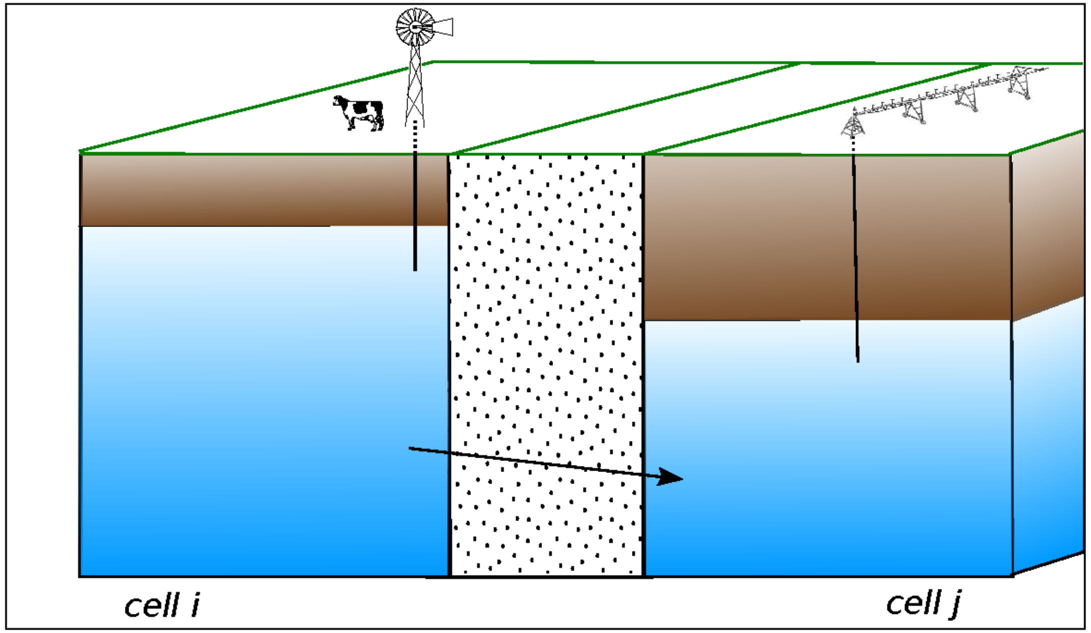
- Worldwide groundwater governance:
  - Most aquifers are de-facto open access
  - Concern about unsustainable use
- Supply and demand:
  - Where water is abundant or people scarce, problems are limited
  - For 80% of world’s aquifers, extraction<recharge (Gleeson et al. 2012)
- Externalities:
  - Economists long viewed groundwater as a big pool, with little benefit from management
  - Spatial heterogeneity of resource suggests large, local externalities
  - Management is best explained as addressing these externalities

This Presentation

- Framework: externalities and local governance
- Governance and collective action
- Global aquifer comparison
    - 11 aquifer systems across six continents
- Illustrative cases of local externalities and management

The Common Pool Problem

- Pumping without externalities presumed efficient
  - I.e. as if each cell is walled off underground
- “Non-sustainable” extraction is inefficient when resource is shared
- Some controversy over extent of competition
  - Lab results support myopic pumping assumption



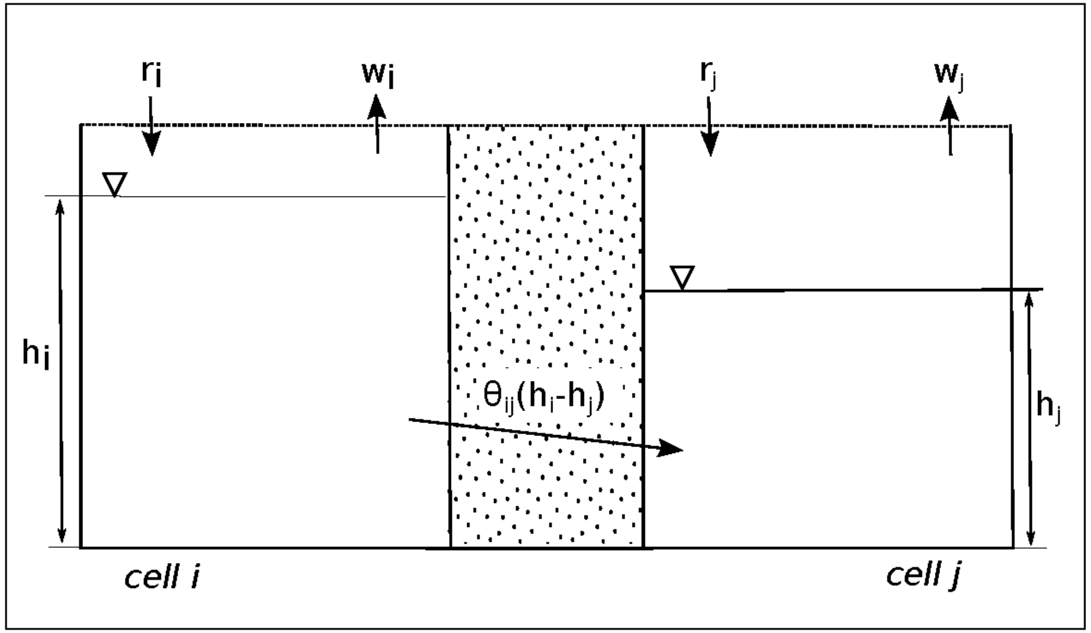
The Nature of the Problem

- Maximize net benefits, where:

$$NB_i = \int_0^T \pi_i(w_i, h_i)e^{-\delta t}dt$$

$$\dot{h}_i = r_i - w_i - \theta(h_i - h_{-i})$$

- θ captures the aquifer properties that determine flow between wells
  - Flow increases with greater head
- The common pool problem is fundamentally local



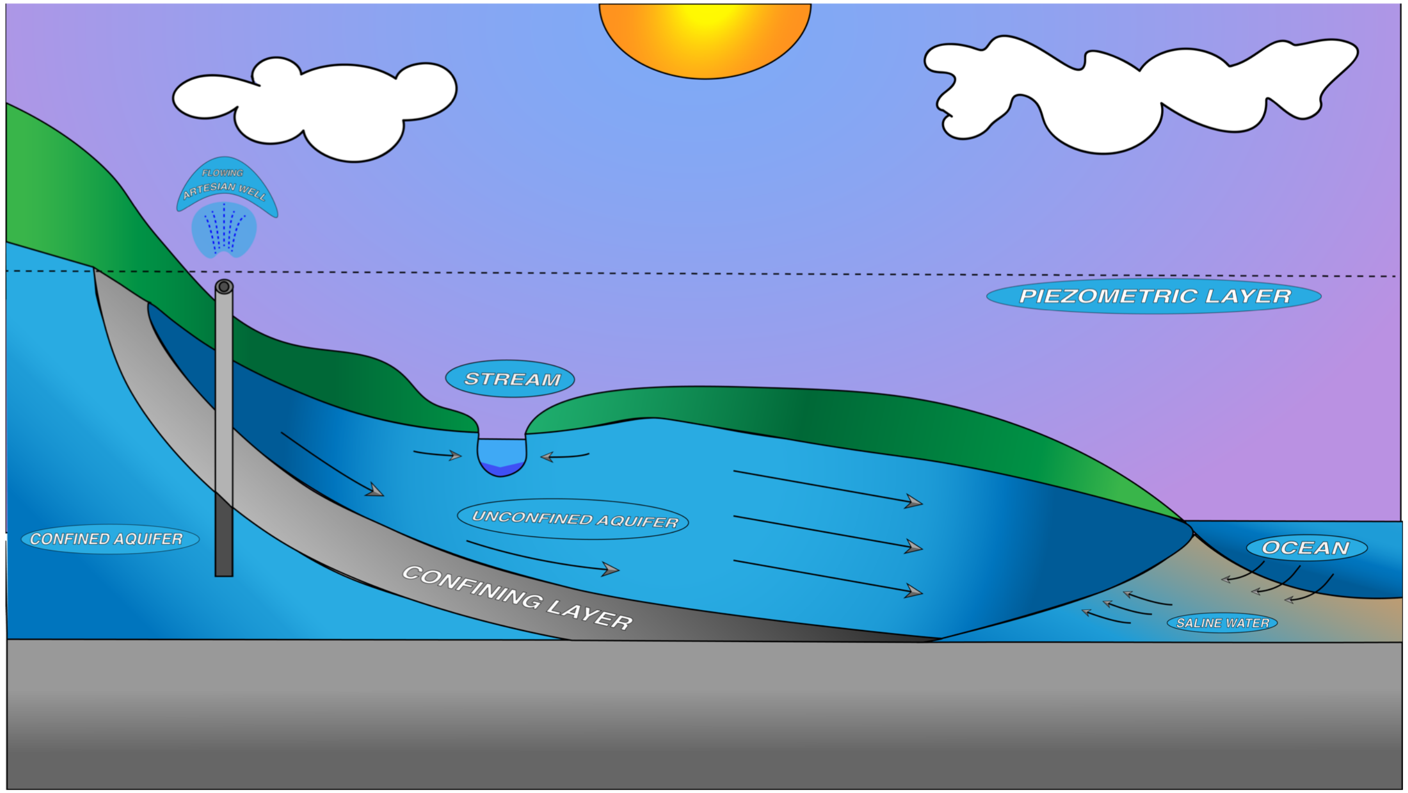
Addressing Local Common-Pool Problems

Elinor Ostrom

Local CPR governance is often achieved with limited state-intervention

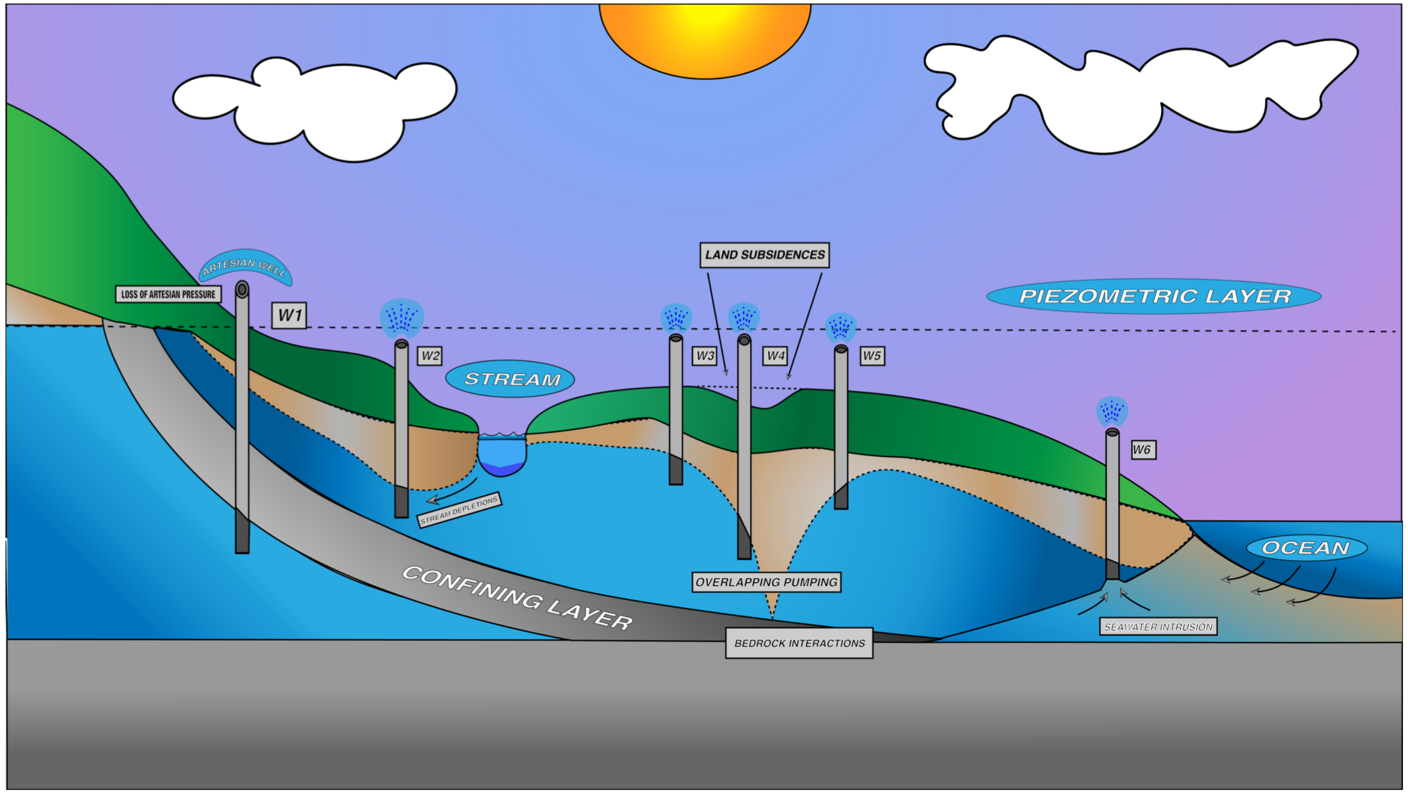
1. Clearly defined boundaries
2. Congruence between rules and local conditions
3. Participation in collective choice arrangements
4. Monitoring
5. Graduated sanctions
6. Conflict-resolution mechanisms
7. Minimal recognition of rights to organize
8. Nested enterprises

Groundwater Systems



- What is an aquifer if not an underground pool
- Water is typically flowing (slowly)
- Systems are complex
  - Gaining/losing streams
  - Confined/unconfined aquifers
  - Saline aquifers
- Sears, Lim, and Lawell (2017)
- Koundouri, Roseta-Palma, and Englezos (2017)

Groundwater Systems



1. Loss of artesian pressure
2. Bedrock interaction
3. Stream depletion
4. Rapid drawdown
5. Land subsidence
6. Seawater intrusion

$$NB_i = \int_0^T [\pi_i(w_i, h_i) - E_i(h_i)]e^{-\delta t}dt$$

What Prevents Collective Action?

Resource value → Stronger controls

- Scarcity:
  - Less Water ←→ Greater Demand
- Institutions can be changed
  - As scarcity rises, more controls are likely to be adopted
- Benefits must exceed all costs of making transition (Demsetz 1967)

Transaction costs → Weaker controls

- TC prevent or delay solutions to CPR problems (Libecap 1989)
- Factors increasing TC
  - Number of users in settlement
  - Information asymmetries (complexity of resource)
  - Heterogeneity of users
  - Skewness of share allocations

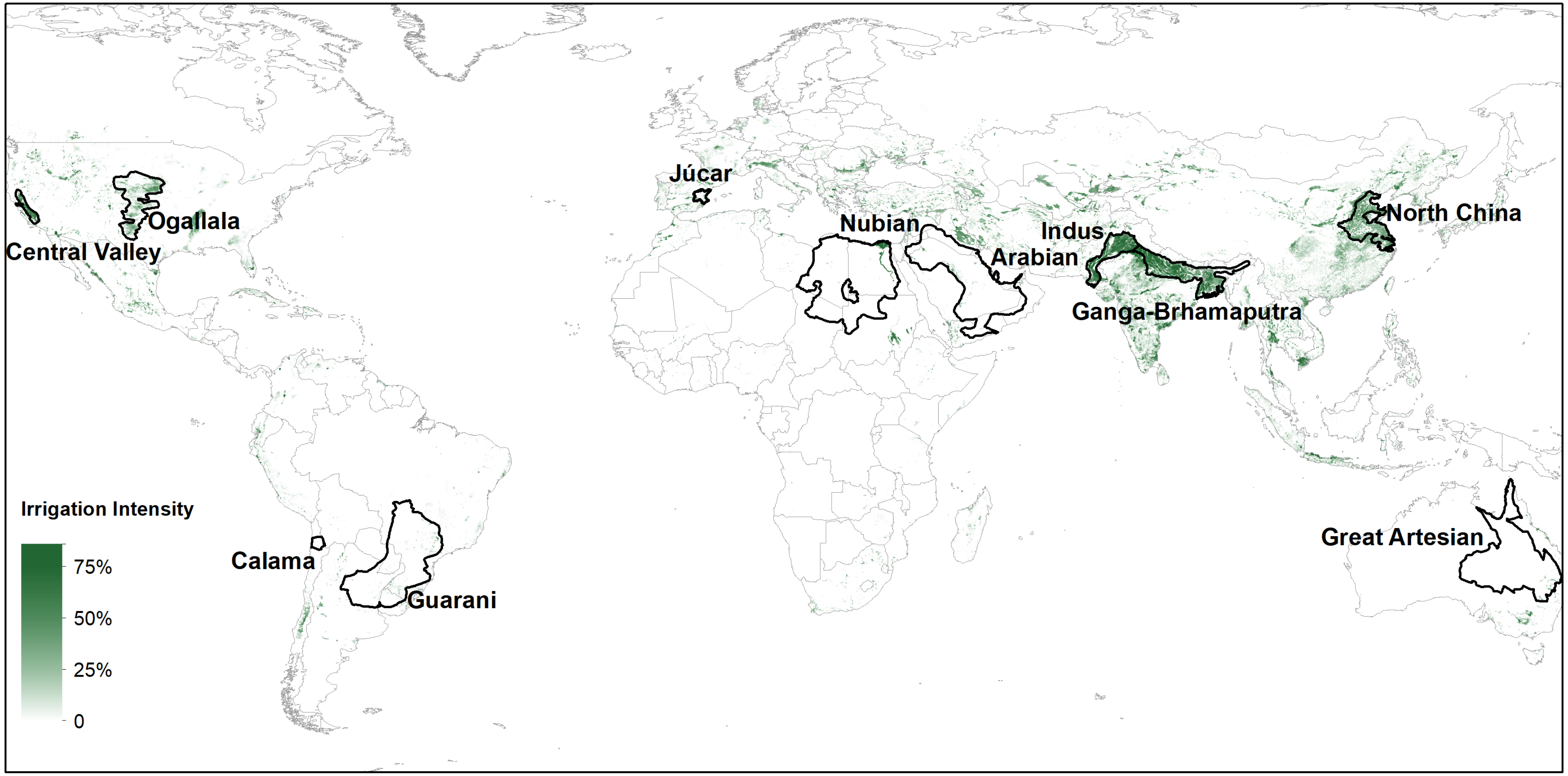
Stages of Management

Progression	Description	Evaluative Literature
Stage I		
Open access	Few or no limitations on pumping	Kanazawa (1992)
Stage II		
Management entity formation	Formation of districts, councils, etc. to promote conservation, define scope of problem, advocate	Edwards (2016); Ayres et al (2018); Nachbaur (2007)
Well permits/entitlements	Control of right to drill and maintenance of well database	Guilfoos et al. (2016)
Well spacing	Minimum distance requirements for new wells	Edwards (2016)
Stage III		
Area closure rules	Stop issuance of permits for specific regions	Edwards (2016)
Well monitoring requirements	Mandatory metering of wells	Babbitt et al. (2018)
Well retirement	Removal of well from production	Tsvetanov and Earnhardt (Forthcoming)
Groundwater recharge	Investment for artificial replenishment	Harou and Lund (2008)
Local uniform rules	Cutbacks or pricing implemented uniformly	Smith et al. (2017); Drysdale and Hendricks (2018); Huang et al. (2013)

Stages of Management

Progression	Description	Evaluative Literature
Stage IV		
Binding pumping caps	Limits on total basin extraction and assignment of individual pumping caps	Ayers et al. (2018); Ayers et al (2019)
Punitive rule enforcement	Monetary or other penalty for excessive withdrawals	Halder (2019); CA Water Code 100732
Stage V		
Groundwater banking	Storage and ownership of recharged groundwater	Guilfoos et al. 2016
Groundwater markets	Transfer of pumping rights	Kuwayama and Brozović, (2013); Brozović and Young, (2014); Edwards et al (2018); Wheeler et al. (2016); Manjunatha et al. (2011)

Aquifer Systems in Our Study



System Comparison

Basin	Primary Countries	Extent (1,000 km^2)	Thickness (m)	Period	Depletion (km^3)
Ogallala	United States	450	150	1900-2008	353
Central Valley, CA	United States	80	600	1900-2008	113
North China Plain	China	320	1,000	1900-2008	170
Northern India System	India, Pakistan, Nepal, and Bangladesh	~920	600	1900-2008	1,361
Guarani	Argentina, Brazil, Uruguay, Paraguay	1,200	800		
Júcar Basin	Spain	8			
Calama	Chile	0.6-0.8	210		
Arabian Aquifer System	Saudi Arabia	>1,485	6,500	1900-2008	468
Nubian Aquifer System	Egypt, Libya, Sudan, Chad	2,176	3,500	1960-2000	~40
Great Artesian Basin	Australia	1,700	3,000	1880-1973	25

Global Groundwater Governance

Basin	Recharge (km³/yr)	Use (km³/yr)	Stock (km³)	Recharge Ratio	Stock Ratio	Externalalities	Observed Stages
Ogallala	6-8[3]	~17	15,000	2.43	0.12%	LD, SF, BR	II-V
Central Valley, CA	7[3]	~11	1,130[3]	1.57	0.97%	SF, LD	II-III
North China Plain	49.2[3]					LD, SU	II
Northern India	176[1]	230[2]		1.31		LD, BR, RI	I-II
Guarani	45-55[6]	1.0[5]	30,000[5, 6]	0.02	0.003%	-	I
Mancha Oriental	0.28-0.33[7]	0.3-0.45[7]				SF,AP	II-III
Calama	0.2[4]	0.3[4]		1.5		SF	V
Arabian	1[3]-2.76[2]	16[2]	2,185[2]	5.8	0.62%	LD,SI	II
Nubian	-0.2[1]	2.2[1, 2]	14,470	NR	0.015%	RI,SF	I-II
Great Artesian	~1	0.55[2]	8,700	0.55	0.0063%	AP	I-III

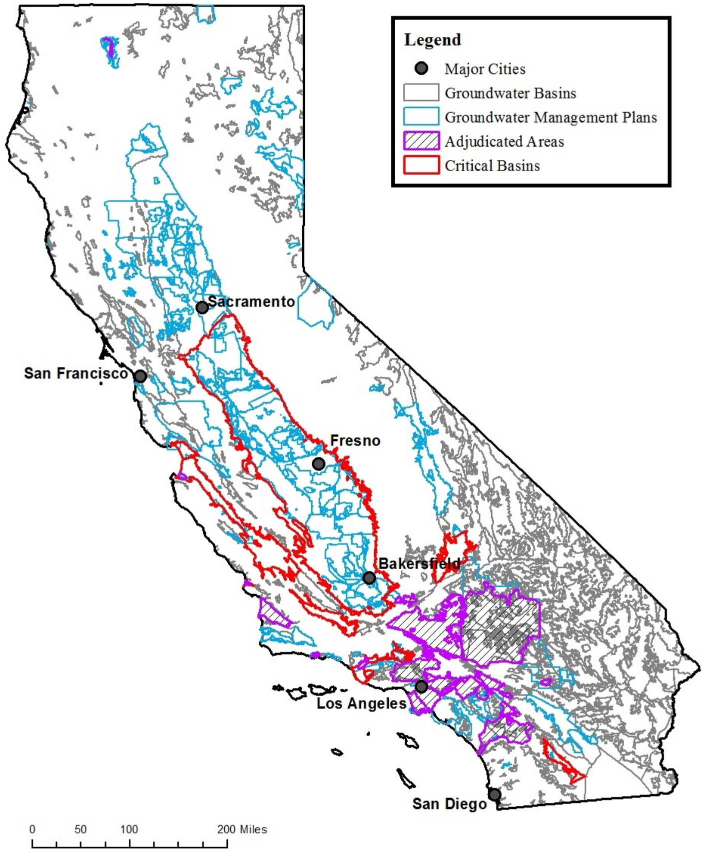
LD-local areas of rapid drawdown, **BR**-bedrock interactions; **SU**-land subsidence; **RI**-loss of buffer to mitigate risk; **SI**-seawater intrusion; **AP**-loss of artesian pressure

Case Studies: Institutional Transitions

High Plains: Transition to Steps II and III

- 1950s and 1960s Kansas: Local areas of rapid depletion
- Well permits prove ineffective at preventing "wild west"
- Groundwater users petition state for local control
- Five groundwater management districts
    - Well spacing and area closures
    - Local areas of uniform cutbacks

Central Valley: Barriers to Stages III-V



- 10 designated critical basins
- Would benefit greatly from management approaches from stages III-V
- Transaction costs impede and delay transition:
  - Larger basins
  - Heterogenous users
- Fractionation in governance approaches

Calama: Ongoing Challenges of Steps IV and V

- Calama aquifer system in the Atacama Desert of northern Chile
- Northern Chile produced about ¼ of world's copper
- Tradeable property rights to water
- Indigenous communities face diminished water supply
- Disputed accounts of sustainability of water extractions

Discussion

- Groundwater problems are local
- Governance is an effort to address externalities
- Transaction costs can impede effective management
- There are no panaceas
  - No examples of effective, exclusively top-down management
  - Yet, the allocation and rules associated with central governments partially determine transaction costs