Accounting for the Human Impacts of Over-Exploiting Aquifers with Deteriorating Water Quality in Semi-arid Regions

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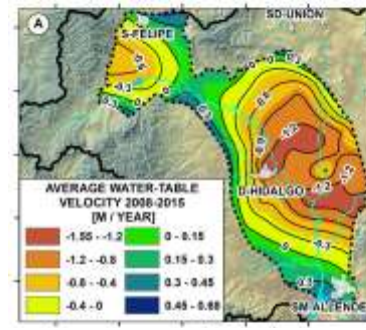
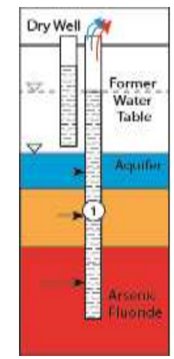
Impacts from Over-Exploiting an Aquifer System in a Semi-arid Region



1. Falling <u>water tables</u>
   - Drives up electricity costs for pumping
   - Forces people to expensive new wells
2. Deteriorating <u>water quality</u>
   - Accessing deeper, older more mineralized water
     - Higher Total Dissolved Solids (TDS)
     - Higher Geogenic Arsenic Concentrations
3. Human development
   - Decreasing Childhood IQ
4. <u>Wealth</u>
   - Household Income
     - Drinking water quality mitigation costs
   - Agricultural Industry
     - Rising Energy Costs Decrease Profits

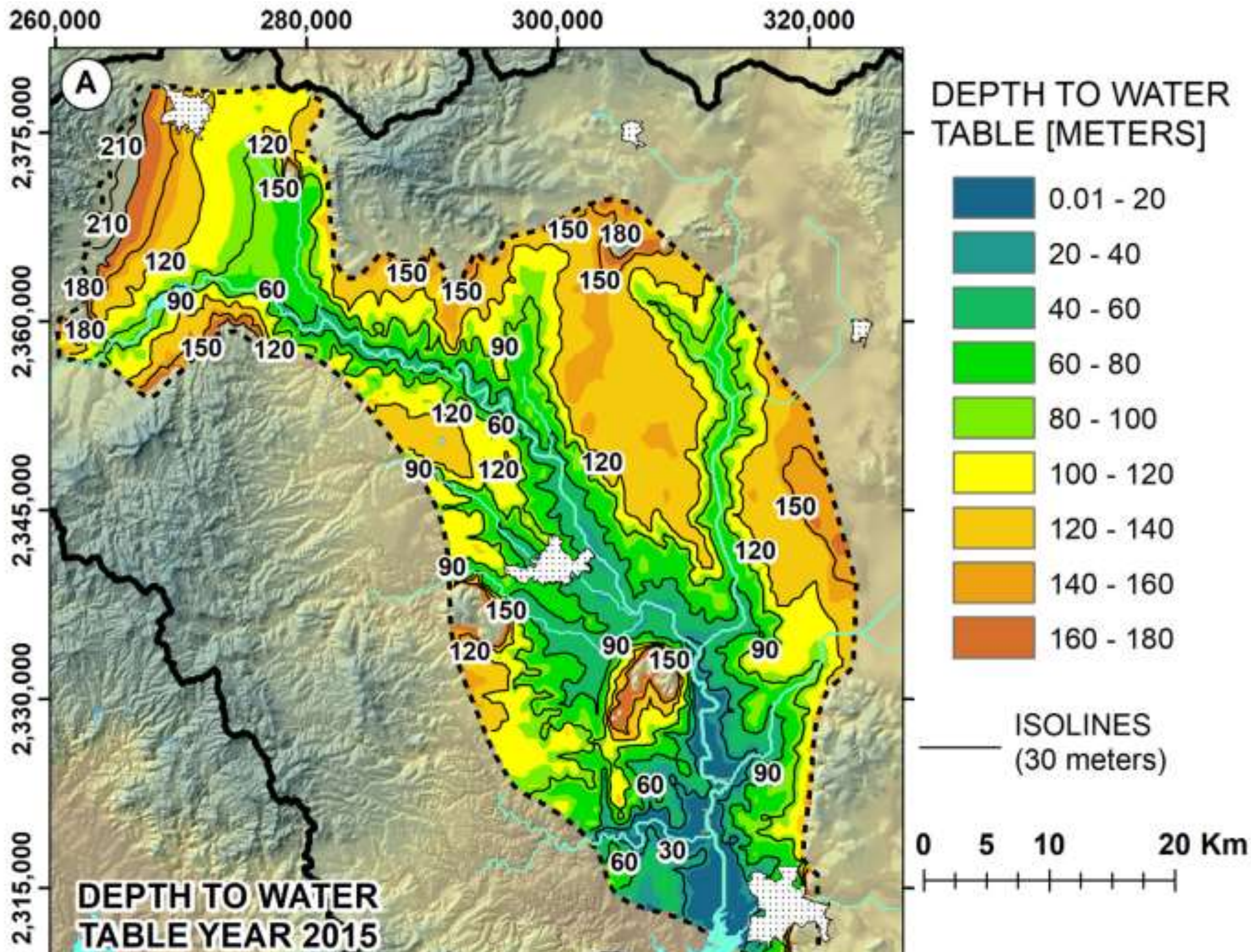


Objective

- Understand the long-term impacts of intensive irrigation pumping of aquifers on human health and economic development in regions solely dependent on groundwater.

Study Area

1. Falling Water Tables

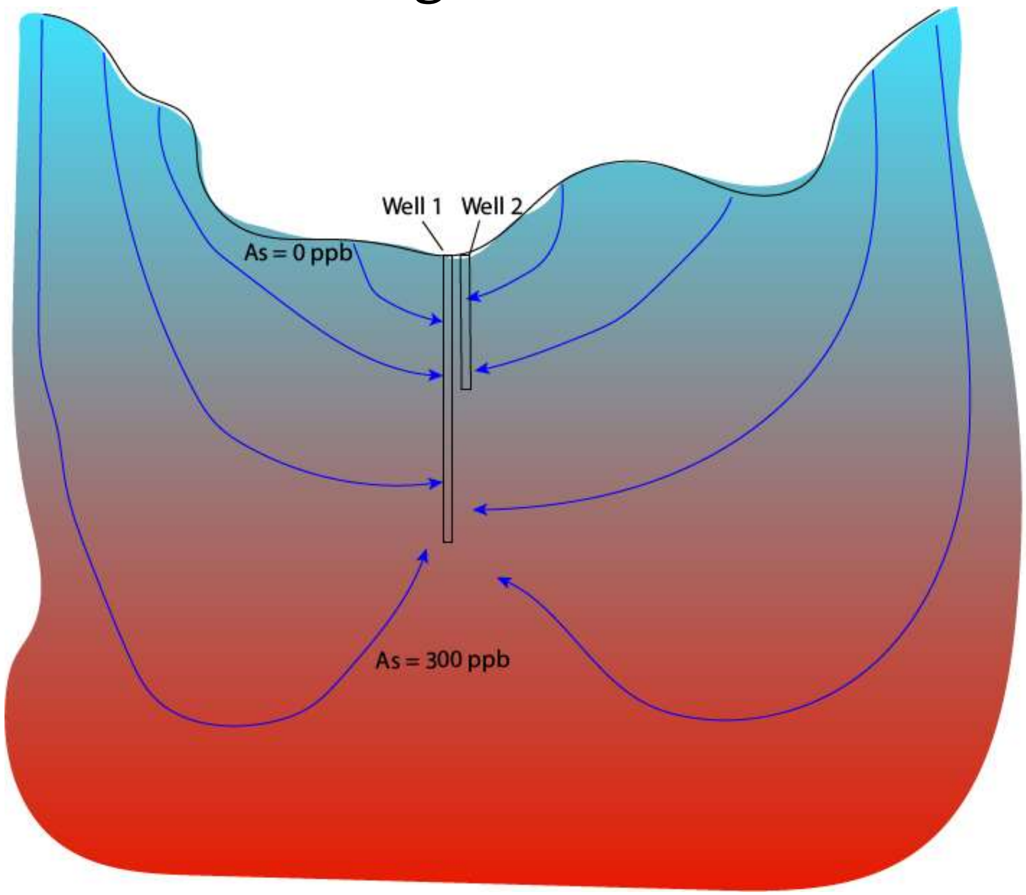


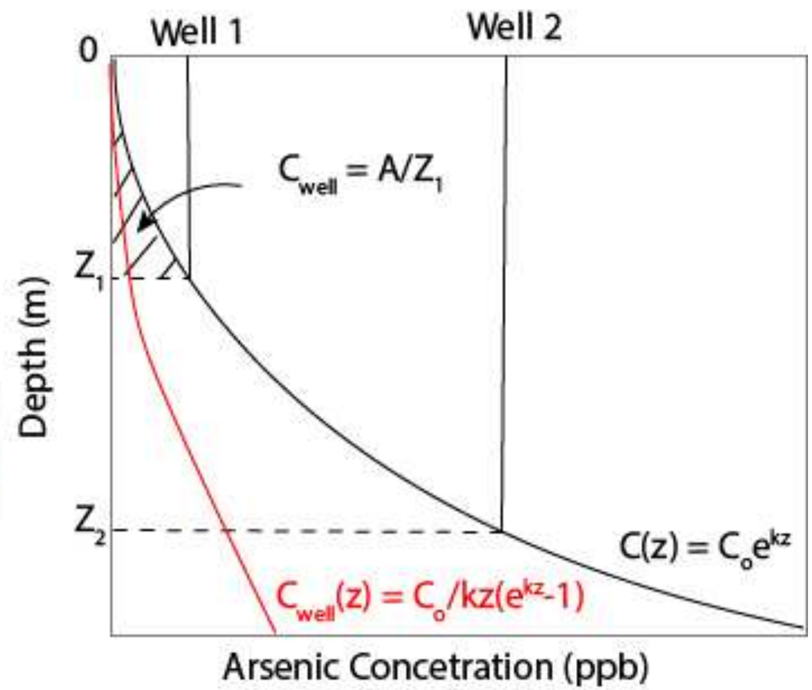
By 2040 most of the aquifer will be un-economical for agricultural use without large subsidies.

Li et al., *J. Hydrol.*, 2020.

2. Deteriorating Water Quality

Rising Arsenic Concentrations with Well Depth





$$C(z) = C_o e^{kz}$$

Variables

z - depth below ground surface [m]

C(z) - arsenic concentration at depth [ppb]

C_o - arsenic concentration at surface [ppb]

C_{well} - integrated arsenic concentration [ppb]

k - rate of increase in arsenic with depth [m^{-1}]

$$C_{well}(z) = \int_0^z C_o e^{kz} dz =$$

$$\left(\frac{\frac{C_o e^{kz}}{k} + a}{z}\right) - \left(\frac{\frac{C_o}{k} + a}{z}\right) = \frac{C_o}{kz}\left(e^{kz} - 1\right)$$

2. Deteriorating Water Quality

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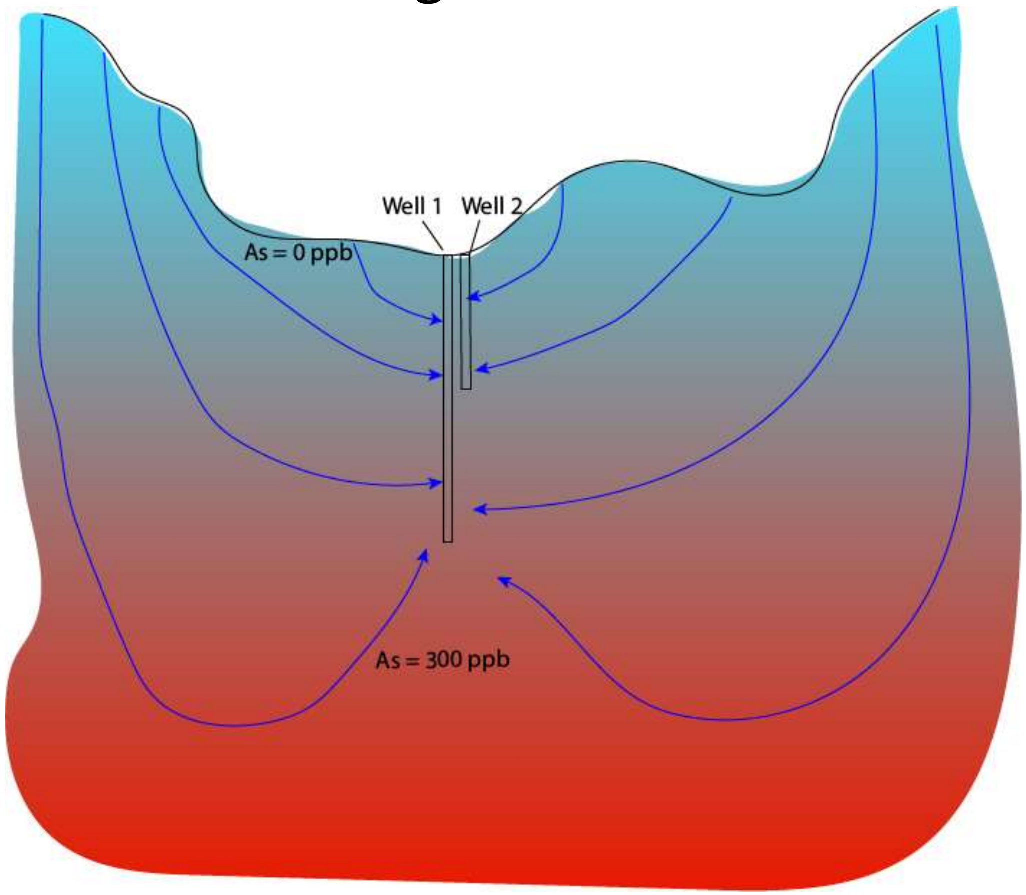

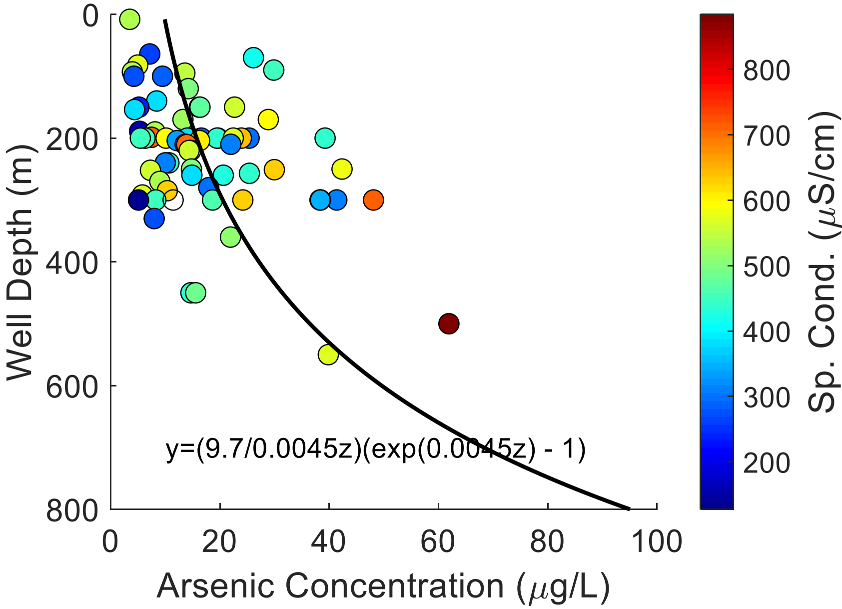

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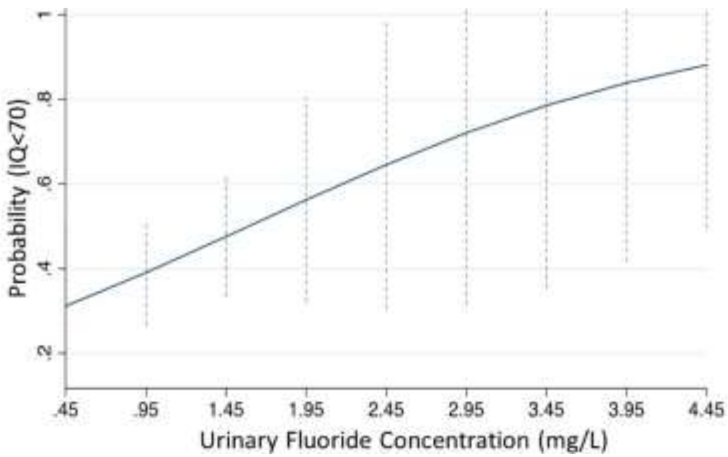
3. Human Health and Development

Estimating Lost Lifetime Earnings from Exposure to Arsenic and Fluoride



Probability of having an IQ<70 in relation to urinary fluoride concentrations in 6-12 year old children (Farias et al., In Prep.).

One study found 1 μg/L increase in As in drinking decreases IQ by ~6% (*iq* = 0.06)

$$IQ = iq(\log_e As) + IQo$$

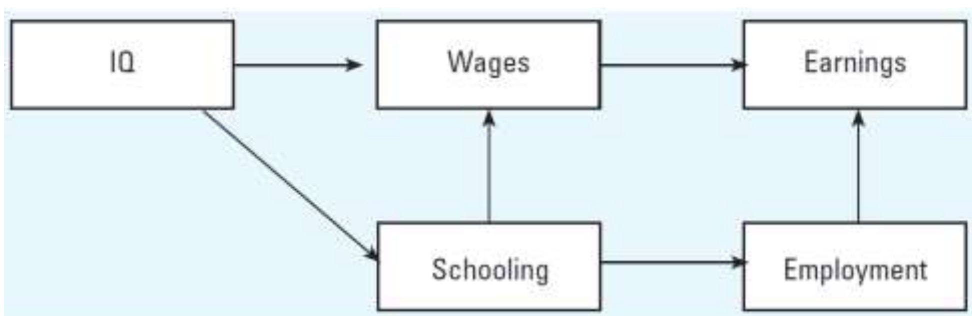
Rocha-Amador et al., *Cad. Saude. Publica, 2007.*

Each IQ point reduction below 100 was estimated to result in approximately 2% per capita economic output (RIQ = 0.02).

$$k_{IQ} = R_{IQ}(IQ - 100)$$

Attina & Trasande, *Environ. Health Persp., 2013.*

Minor IQ reductions may have big impacts on lifetime earnings.



Grosse et al., *Environ. Health Persp., 2002.*

4. Negative Impacts on Wealth

From Mitigation Costs

1. Decrease rate of pumping
   - Improving Irrigation Technology
2. Filtration
   - Ferric Oxide
   - Reverse Osmosis
3. Alternative Sourcing
   - Rainwater Harvesting
   - Bottled Water

Flood Irrigation

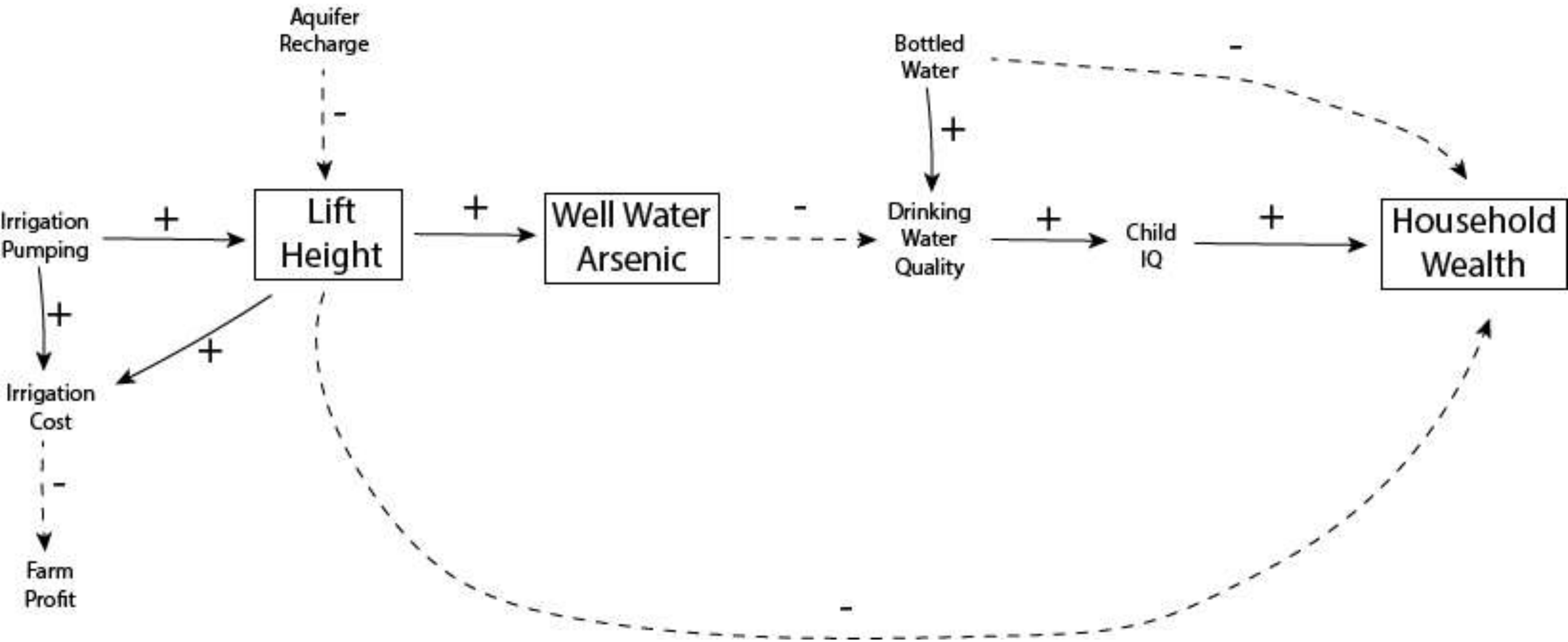
Household Ferric Oxide Filters for Arsenic

Wellhead filtration to lower TDS for irrigation

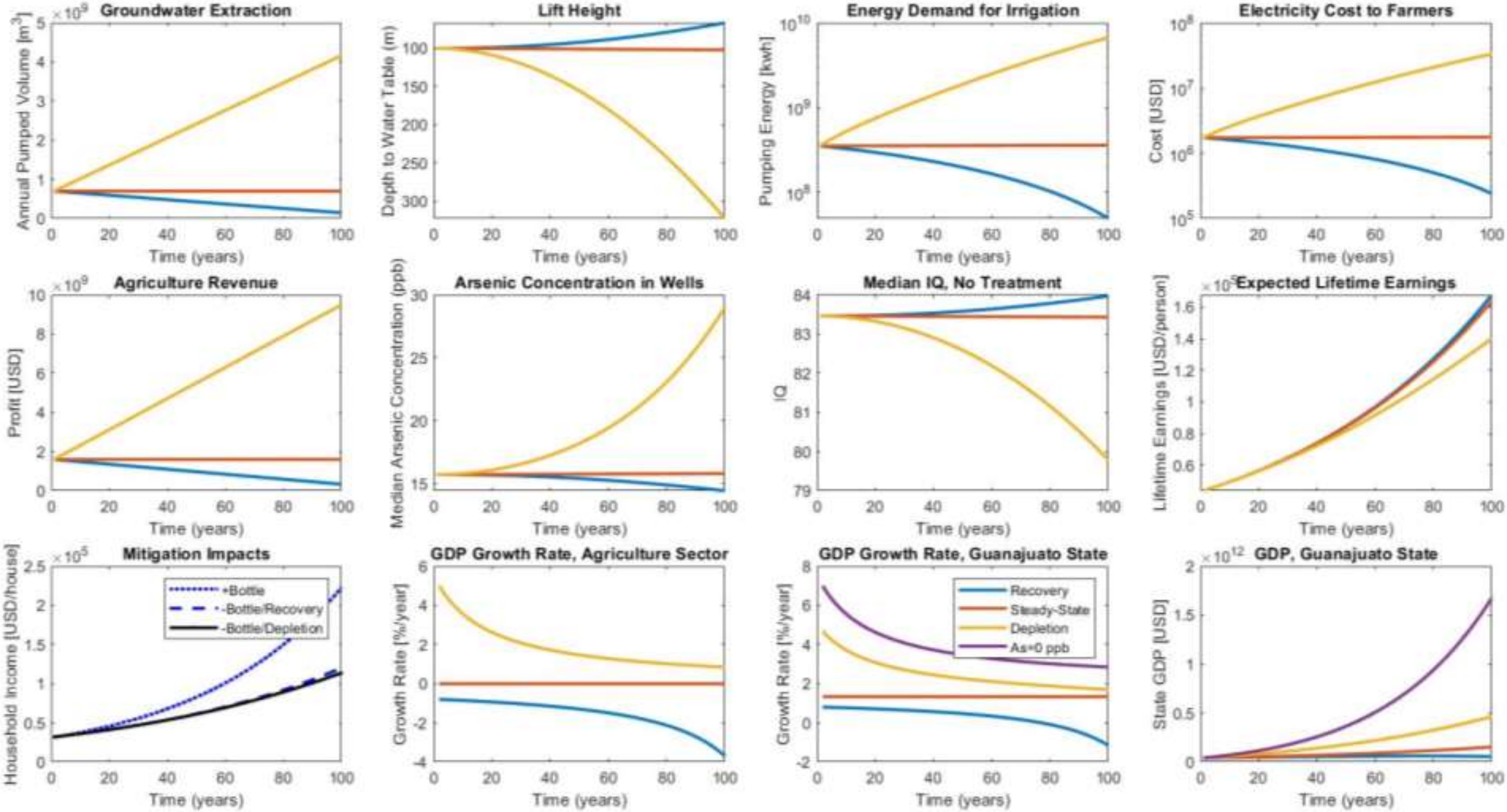
Bottled water for family of five = 634 USD/yr

Water quality mitigation increases burden on households for safe drinking water.

Dynamic Systems Model



Social and Economic Impacts of Over-Exploiting Aquifer



Assumes 3 scenarios: 1) Water Table Recovers, 2) Water Table Remains at Steady-state, 3) Depletion Continues (most likely)

Conclusions

1. Falling water tables lead to a host of problems down the road in a region that is exclusively dependent on groundwater
   - The *impacts and recognition* of these problems have long time lags that hide the true externalities of big agriculture production in arid regions
2. The cost of mitigating exposure to arsenic are large relative to household income (~5%), but the economic return on investment in mitigation over a generation for the individual and the state are high
3. Even with the most optimistic aquifer recharge rate of 0.16 m/yr, the recovery of the water table will take centuries
4. Lack of systematic accounting of the present and future impacts will delay the full recognition of trade offs and inequalities from over-exploiting an aquifer

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